Kline-Anderson, Inc.

Review of Schedule and Resource Requirements to Develop a HydroCatalysis Functional Prototype Unit

Final Report for
Technology Insights

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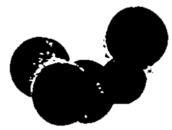 

Apparently there is color, apparently sweetness, apparently bitterness; actually there are only atoms and the void.

Democritus 420 BC

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1. Introduction

Objective:

The scope of work for this technical evaluation contract consists of the following:

> "Review the current status of the HydroCatalysis process development and plans for development of the functional prototype unit, and provide comments and recommendations regarding the planned tasks, resource requirements and projected schedule."

The subtasks for completing the review were broken down into four areas, that are addressed below. COMCO has defined four stages in the "Commercialization Investment" of Dr. Mills's new hydrogen energy source (Attachment A). Kline-Anderson has been asked to provide a "reality check" or a "sanity check" on the Phase I development program, and "red line" the schedule that comprises the first of the four stages (Attachment B). The descriptions of the Test Cells 1, 2 and 3 which were initially given to me were outdated, and needed additional work and recasting. Clarification of what these milestones are was necessarily an integral part of my task. The resultant redefinition of these milestones was finalized by Jim Kendall and is included as Attachment C.

As part of a Due Diligence process that has a bearing on funding levels and timing (staged funding). We (Kline-Anderson) take a conservative view of the technical aspects of this project. I have based my report strictly on my fact finding trip with Jim Kendall to HydroCatalysis Power Corporation (HPC) and the NovaTech labs, and the written information provided to me. In this role, I have been mindful that considerable investment funds are contemplated, and the planning that describes how these funds will be utilized is key to ensuring that resources will be used effectively and efficiently and towards the absolute success of COMCO. We have deemed it wise to err towards the conservative, allowing Technology Insights and PacifiCorp to make up their own minds about how much optimism to inject. Where I did not see a clear process underway, I have pointed that out so that Technology Insights, who has access to many more documents relevant to this technology, and who have months of study behind them about this technology, can incorporate my comments into the total picture.

Most importantly, the alterations in the revised schedule result in a planning document that represents the most likely outcome of the work to date at any given time in the progress of the work. Milestones have been revised to be natural breakpoints in the progress of work, so that now slips or advances in the work schedule may be easily accommodated. This schedule will continue to serve as a working document for tracking results of the investment, and can form the basis for allocation and reallocation of resources along the way. The intention is to provide COMCO management with additional information and working tools to ensure the overall success of this venture.

2. Review Background Material (Subtask 1)

A list of the documents I received and reviewed is in Attachment D.

My study was a technical evaluation of the process to commercialize this invention only, and I have not done a technical review of Dr. Mills's Hydrino Theory, or of the experiments that lead to the design of the vapor-phase reactor. For the purpose of this study, I have assumed that excess heat is evolved by these energy cells, that this result has been verified by independent laboratories, and that the phenomena is explained by Dr. Mills's Hydrino Theory. I reviewed all items in Attachment D only, thus, I have not reviewed the data or experimental methods from this previous work, which goes back several years. Neither have I attempted a review of Dr. Mills's Theory. Therefore I am not opining on the experimental history, or the theory in this report.

However, I saw nothing during my fact-finding trip that contradicted the assertions and representations made by HPC about any of their work, or about Dr. Mills's theory.

3. Visit to NovaTech and HPC Facilities to review the current status of activities relevant to the integrated schedule for development of a functional prototype unit. (Subtask 2)

As explained to me in my visits to HPC and NovaTech, by their personnel, and in conversations with Jim Kendall of Technology Insights, the HPC/NovaTech current plan as outlined is the following (points A through D):

(A) The most long-lived excess heat cell experiments were completed at Thermacore. Multiple experiments at Thermacore demonstrated excess power, but the work was abandoned because the results did not provide a basis for a commercial application.

The electrolytic cells were rejected as a design basis for a commercial unit due to the limitations in power density that they could achieve. In seeking economically viable power densities, the concept of the hydrino transition reaction was re-examined and a new energy cell design was invented from first principles. HPC asserts that the transition reaction can occur in the gas phase, as well as in aqueous solutions. If this assertion is proven true, this enables a new generation of hydrino energy cells to be built that take advantage of traditional chemical process ideas; such as continuous feed of reactants, high operating temperature, and continuous operation.

(B) It is the transition to this new type of cell that is the focus of Test Cell 1 work that is in progress at HPC and NovaTech. The objective of this Task is to demonstrate a cell that will operate repeatedly and controllably. The operating parameters have been defined as:

Operating Parameters
• Catalyst vapor pressure (catalyst concentration) • Choice of catalyst • Choice of hydrogen dissociation surface: filament or foam • Molecular hydrogen gas pressure • Atomic hydrogen gas pressure • Filament operating temperature (current supplied to the filament) • Cell hydrogen flow rate

Optimal operating parameters are expected to be 2 Torr of potassium, 200 milliTorr of molecular hydrogen, and as high a filament temperature as possible to atomize as much hydrogen as possible. (1 atmosphere of pressure = 760 Torr). This information was based on the results of the quartz cell, and calculations by Dr. Mills.

(C) The design goals are listed in Attachment C. Most importantly, catalyst vapor pressure can be varied by controlling the temperature to the potassium iodide oven with an external heater. Previous designs have used heat from the filament to vaporize the potassium. The addition of this degree of freedom will permit the best operating vapor pressure for potassium to be documented. Secondly, hydrogen can be flowed through the cell continually, the first step in going towards a continuously working cell.

(D) Fabrication of a test bed, which I recommend be expanded to a conventional Test Fixture is underway at NovaTech. A Test Fixture will allow experimentation with different operating scenarios, by serving as a standard testing device for different designs of the energy cell. (See Section 4).

HPC Site Visit:

The current activity centers around a dramatic change in energy cell design. In changing design from the aqueous cells to vapor phase cells, the problem of getting atomic hydrogen and catalyst ions in the gas phase had to be solved. Bill Good, HPC's research director, has stated that potassium and rubidium both are active catalysts for the transition reaction process. Further he states that alkali halogens are the best chemical forms to utilize and that several salts were tested, and iodides were determined to be the best choice. According to Mr. Good, an operating temperature of greater than 730 C to keep the ions from condensing out on the walls of the vessel is required. He also presented the following information:

Initial testing was done with a quartz tube reaction vessel. Data from this tube indicate that optimal operating conditions will be 2 Torr of potassium ions, 200 milliTorr of molecular hydrogen with a filament temperature (reaction surface temperature) as high as possible (limit on the tungsten is 2000 C).

Tungsten was chosen as the filament material due to its good high temperature properties. However, tungsten reacts with oxygen, thinning the filament and leading to failure. Thus a good vacuum must be established prior to powering up the filament and introducing the reactants. *The reaction vessel should be evacuated to below the milliTorr levels that are achieved now, and an upgrade from the current mechanical pumping system is required to ensure a clean vacuum free of contaminants.*

Evolved heat is measured by differential calorimetry. HPC and NovaTech have invented a new high temperature calorimeter for this purpose. It is constructed from firebrick, and the energy evolved is measured as a changing heat gradient between two points located radially outward from the energy cell's center. As excess heat is evolved from the energy cell, the rise in temperature differential between the two points is measured. No experimental runs were attempted with any cells until calibration curves for the new calorimeter were stable and reproducible. It is critical to be meticulously careful with these calibrations, since the observable of excess heat will be the chief experimental result that will guide the optimization of these energy cells. *Meticulous thermal isolation and calorimetry that is above question is key to this process. It is the single most important issue for the overall success of the development plan.*

Recommendations:

Because the energy cell is not totally enclosed in the firebrick, but the ends of the cell protrude from it, there are two heat paths out of the cylindrical energy cell: Radially out through the firebrick, and axially out the ends of the cell. Since conduction and convection dominate over radiation for heat transfer mechanisms, it is reasonable to assume that the proportion of heat that flows via each path remains constant throughout any heat generating operation of the cell. If this proportionality does stay constant, then the measurement of excess heat recorded by the thermocouples located radially out from the center of the cell will indicate data accurately. This assumption may or may not hold up with the addition of the tungsten foam as well as it holds up for a simple tungsten filament. Final resolution of this issue will require construction of a "test bed calorimeter" that completely encloses and isolates the apparatus, like the conventional bomb calorimeter.

This test-bed standard calorimeter should be specified with multiple thermocouples, ten or twelve, that are monitored and recorded by a data acquisition system. Design and construction of this device will require additional materials and instrumentation beyond what is presently in place at HPC. This could be incorporated as part of the Test Fixture. *Because the thermal measurements are key to this project, the firebrick calorimeter must be fully characterized and calibrated to a standard calorimeter if possible.* If a commercial calorimeter cannot be brought in for standardization against a well known instrument, an acknowledged calorimetry expert can be brought in to independently study and confirm that the calorimeter is fully functioning appropriately. This expert can certify that the calorimeter is functioning properly, and that it is the best way to handle this high temperature situation.

An inherent limitation of this energy cell is the temperature limit of the stainless steel vacuum vessel. The vapor pressure of KI at 710 C is 1 Torr. To achieve 2 Torr, the temperature must be raised to 730 C. For the grade of stainless steel used, a temperature limit of 760 C has been specified, but Matt Ales at NovaTech is willing to push the limit up to 800 C. *Certainly commercial energy cell units will require an advanced materials solution, and the test cell development program must reflect this.*

Two test cells are slated for operation by HPC (TC1B and TC1C) to improve the understanding of the process by variation of key operational parameters. I have listed these parameters in the box above. *To map the multiple parameter-space of the performance of this energy cell, each parameter must be varied independently and systematically.* This data guides test cell design and will form the basis for understanding the dynamic characteristics of the prototype energy cell, and indicate requirements for process control instrumentation.

In addition to an upgrade of the vacuum system and test-bed calorimeter, additional testing equipment is required. A high quality stable power supply for the filament, additional thermocouples, and a hydrogen flow meter to measure molecular hydrogen delivered to the reaction vessel is a minimum equipment list for this task. At least two professionals full time should be devoted to this effort. A data acquisition system to monitor and record pressures, temperatures, current to the filament, and current to the potassium heater must be incorporated with these testing cells. This is an important step in the development and understanding of this technology and constitutes a conventional lab Test Fixture.

NovaTech Site Visit

The NovaTech team present included Richard (Hawk) Rochow, Matt Ales, and Lewis Walton. They have expanded their space to house this experiment. In our discussion with NovaTech a quartz energy cell encased in fire brick was described. This work was internally funded by NovaTech and designed to be a "quick and dirty" attempt at independent verification of the evolution of excess heat. It was a static system, capable of no gas recharge. Catalysts used were potassium nitrite and potassium iodide, with heat to the catalyst from the filament only: no independent control. Zirconia and alumina were used as insulators in this cell, with a marginal vacuum system. The calorimeter, which was originally constructed of calcium silicate (failure mode: warping), was replaced with the firebrick insulation that forms the basis for the current calorimeter. Here the simple firebrick delta-T method for measuring heat flow was developed. Results indicated 3% excess heat was evolved, with an estimated 2% uncertainty in the measurement.

In designing Test Cell 1, they described numerous significant design changes that were made based on their experience with the quartz cell. The quartz tube was replaced with a stainless steel vessel with an external catalyst reservoir. Internal aluminum oxide insulation was added to protect the stainless steel wall from thermal damage. A tungsten foam core for dissociation of hydrogen was installed to maximize tungsten surface area. Expected maximum centerline operating temperature is 1500 K, with an absolute

maximum at 1800 K, where the alumina will start dissociation. A flowing hydrogen gas system was installed.

Experimentation up to Oct. 16th had not resulted in a statistically significant observation of excess heat. NovaTech proposed several reasons for the failure of the cell to evolve heat. Among them are the following:

- Control of the catalyst location and partial pressure was not sufficient to deliver catalyst to the reaction volume at appropriate concentrations, and at the right moment in the experimental "run" of the cell.
- Large time constant of the calorimeter may be obscuring results.
- Failure of tungsten filament at high temperature and flow conditions.
- Possible contamination of the tungsten foam rendering it inactive for hydrogen dissociation.
- Contamination due to inadequate vacuum.
- Persistent contamination due to alumina insulators.

Recommendations:

To address these issues, they plan to run at higher centerline temperature to achieve greater dissociation of hydrogen gas to atomic hydrogen. They may run with the filament and without the foam. A turbomolecular vacuum pump has been acquired by NovaTech to be fitted to the energy cell. This addition will solve the problems of impurities to a large degree by improving the ultimate vacuum the system can reach, but cannot totally ameliorate the oxygen and water contamination that is the product of the slow outgassing of the thick, hot, alumina insulators. *This is seriously problematic and progress will be faster once the alumina is eliminated.*

A lengthy discussion of the alumina insulation highlighted the fact that it is a source of oxygen and water in vacuo, and due to the size of the insulators, will take a long, *long* time to bake out completely. These insulators will also retard heat flow to the surface of the cell for heat transfer in a heat exchanger. Several other choices for insulation were discussed and molybdenum foil emerged as the early favorite, due to its relatively cheap cost (compared to other advanced materials). *I recommend that this change be effected immediately, in the multi-layer geometry that NovaTech suggested. It will give their cell a higher temperature capability immediately, and speed progress.*

4. Provide comments and recommendations regarding resource requirements for planned tasks leading to the fabrication and initial operation of a functional prototype unit. (Subtask 3)

Test Cell 1

Performance milestone goals require demonstration of excess power over the noise level of the calorimeter (estimated at 2% in the delta T measurement by NovaTech), repeatably and sustained over hours.

Test Cell 1 is currently being modified at NovaTech. Several important issues have been identified that need work-arounds. The most fundamental is the vacuum quality.

While "perfect" mechanical pumps can achieve an ultimate vacuum of 40 milliTorr, this is usually right after a rebuild or general overhaul has been finished, and most pumps only get to 80 or 100 milliTorr, as both NovaTech and HPC have experienced. NovaTech has tried to stretch the quality of the vacuum they get by using the conventional fix: cyclic pumpouts and flushes with an inert gas. This is sound lab practice, and might be good enough if it weren't for the alumina insulators, which present a lengthy outgassing problem due to their thickness. Even after a reasonable "bake-out" period, oxygen and water due to the alumina may persist. *The NovaTech solution, to go to greater pumping capacity is a right choice. If they continue to flush with an inert gas, they might try dry nitrogen instead of helium, because it is cheaper.*

Thermal isolation of the energy cell and the firebrick calorimeter has been discussed above. I recommend that the firebrick calorimeter be redesigned for complete encasement of the energy cell, and calibrated to a known standard. This will be involved, but will pay off with increased accuracy in measurements. *The time constant of the calorimeter (response time) must also be clearly demonstrated, so we will know if results are being obscured.* NovaTech is already considering this problem by comparing the centerline temperature excursions to the delta-T measurement. The uncertainty in the delta-T measurement must clearly be established at 2%. This can be accommodated within the Test Fixture.

A significant materials problem has become evident in the operation of this test cell: The entire reaction vessel must be kept above the condensation temperature of potassium iodide (melting point 682 C). The operating temperature selected to achieve the desired vapor pressure of potassium ions in the cell is 710 to 730 C. Inorganic salts are not known for their reflux tendency back into a furnace, and it is unlikely that a substantial liquid phase of KI is resident in the cell. If the potassium ions or KI molecules were condensing out on any surface below 682 C no positive results in excess heat will be observed due to the absence of the reactant. Further, the potassium must be a lone ion to participate in the hydrino transition reaction. The clear indication is that the entire reaction vessel must be operated at temperatures of at least 730 C, and probably higher. In a commercial energy cell, higher operating temperatures (at the surface of the cell) are desirable, as this gives the cell superior heat transfer efficiency, *so solving this problem sooner rather than later is wise.*

The alumina insulators can probably be run at the desired temperature - however, due to their mass and geometry, it will lengthen the time for the cell to achieve thermal equilibrium at the operating temperature. Further, the problem of oxygen and water contamination from the alumina remains. Direct lab experience in scaleup operations requiring alumina material as pass through insulators or internal static separation units, underscores the need for lengthy bakeouts. The porosity of this material allows outside atmosphere to permeate it each time the vacuum is vented. *In this case the problem is critical enough that we recommend replacing it as soon as possible to ensure accurate results in testing.*

The proposed solution from NovaTech is to fashion a multiple foil insulator to protect the stainless steel walls from excess heat. This is a good solution for Test Cell 1 and should be implemented now. Not only is the thermal problem solved, but the contamination problem is eliminated, and the design for the cell is simplified. In the commercial cell, the vacuum wall itself must be fabricated from an advanced material. *It is prudent to begin testing and evaluation of materials now, as heat shields, in preparation for selecting the final reactor vessel material. This is a serious problem and will take some time to address fully.* It comprises a significant modification to the cell, therefore after its implementation the cell must be recalibrated with control runs. NovaTech estimated the cost for molybdenum foil to effect this change at about $15,000 for one cell. This may be underestimated, and this will be a one-time purchase, but if this solves the problem a much larger purchase of it will be needed.

Test Cell 1	**Objective:** To achieve a design of a cell that will operate repeatedly and controllably, and use as a basis to formulate a strategy for subsequent cell development
Design Goals:	**Status:**
Independently control catalyst vapor partial pressure (utilize an externally heated reservoir, no high temperature seals).	An external heater has been fitted to the catalyst reservoir, converting it into an oven.
Utilize a flowing hydrogen cell (prevent "fuel" starvation).	Hydrogen flows in to the reactor through the catalyst furnace.
Overcome the thermal limitations of previous vessels & insulation (keep stainless steel vessel sufficiently cool, but keep stainless steel vessel hot enough so potassium iodide catalyst precipitation is reduced).	Undergoing redesign and modification now, see above. Ultimately will require fabrication from advanced refractory materials.
Design and fabricate a relatively inexpensive test bed (allow for high surface area tungsten foams or powders, allow for various catalysts, investigate other materials, investigate different operating scenarios (T, P, flow, etc.)).	The initial model is in place at NovaTech, but requires a higher quality vacuum system and instrumentation linked to a data acquisition system to record results of different operating scenarios. See "Fabrication and Operation of Test Fixture" below.

To operate at these elevated temperatures all viton seals must be replaced with metal seals. This will require machining new flanges, and may require machining a new stainless steel reactor tube.

The best control protocol must be agreed upon and used consistently. *A non-dissociating heat source should be considered for control runs of the calorimeter.*

After the above modifications are completed and the energy cell is operating, it is reasonable to presume that one or more iterations of design and modification will be required. This will slip the schedule for Test Cell one considerably.

Other technical additions that NovaTech proposed and I also recommend are the following:

- Data acquisition system: to track thermocouples, gas flow, and current supplied to filament.
- Improved catalyst pressure control
- Attempt to eliminate catalyst losses to cool spots.
- Delta-T thermocouples at faster responding locations (and more than two)
- Greater range in power supply/controllable constant power source.

I estimate minimum personnel requirements for the NovaTech team at 4 people full time. This is significantly higher than their current level of effort.

Fabrication and Operation of the Test Fixture, TC1A and TC1B:

The concept of the Test Bed is important and should be expanded to be a conventional Test Fixture. The last design goal for the Test Cell 1 is to fabricate a test fixture to investigate operating scenarios (parameters). Instrumentation needed for optimization of the process will include the following: A constant power - power supply, additional pressure gauges, pumping system upgrade to improve the vacuum (impacts impurity level in the cell), and metering to monitor hydrogen gas flow into the cell. Acquisition of a residual gas analyzer to determine content of the reaction cell should be seriously considered.

This test fixture, instead of being an operating model, serves as a standard testing device for different designs of the prototype energy cell. It will support the development of auxiliary control systems to service the steady state and dynamic requirements of the energy cell (Test Cell 2 performance goals).

It will generate comparable test data all the way along the program, for each change in the energy cell. An automatic data acquisition system run by a dedicated computer is integral to this fixture. It measures all important operating parameters, including amount of reactants delivered over time to the cell, pressures, heat signatures from thermocouples from digital meters, etc. This is all saved to disc *for every test run*. A graphic paper printout of the data portrays different variables over time. This record-keeping provides a record that documents progress and shows whether milestones are being achieved. It

records a complete data set for analysis and troubleshooting of problems. This test fixture is common lab practice and requires standard instruments.

It is unwise and ill-advised to use a test cell that is incrementally modified and integrated into its own data gathering system for this purpose because any problem that may have occurred that was overlooked can skew results. A test fixture is a work station that, for example, has a multi-lead cable that is plugged into the energy cell under test. It is advisable that the firebrick calorimeter be a permanent part of the test fixture itself. The test fixture houses the metering devices and data acquisition system.

The redesign of TC1A and TC1B as independent test fixtures, with calorimeters that are calibrated to a standard, creates a data acquisition system that records all experimental events, and the results are kept in lab notebooks. This is useful for a number of reasons, among them financial and experimental, and for demonstration purposes. For demonstration to third parties, who will eventually want to see this data (OEM's), it provides a standard lab unit where all cells have been evaluated with results that are easily compared to each other. *This issue takes on even more significance since Test Cell 1 hasn't produced a positive result yet, in terms of excess heat.* As soon as the cells start generating excess heat, baselines for operations and outcomes will be automatically recorded in the test fixture, facilitating the optimization, and design/modification cycle.

This level of documentation - at each step - increases the overall probability of success of the Phase I program, and lays a foundation for interaction later with OEMs. A person with extensive laboratory experimental experience (advanced degree), and extensive management experience should be put in place to provide strong leadership to the design and testing teams. This leader will keep teams on task, and get them the materials/resources they need for quick work-arounds in between milestone reviews with management.

Conclusions:

The level of professionalism and care displayed by the NovaTech personnel is high and consistent. They appear organized, thorough, thoughtful and prepared to go forward. They have made a business based on prototyping hardware for space applications, which makes them experienced not only in hardware design and methods development, but in working with extreme operating conditions. In the case of space systems, hardware must withstand extremes of temperatures and pressure along with the possibility of frequent thermal cycles. This group is very well-qualified to lead the Test Cell development team and engineer these cells for scientific accuracy as well as functional reliability with a continual awareness of the requirements of the eventual commercial unit. They are a key resource for this project, and the depth, scope and experience that they bring to their work substantially increases the likelihood of the absolute success of this entire Phase I development program.

Their team would be more effective if it were augmented in several ways. They need an expert calorimetrist available to them for quick consultation concerning the operation and calibration of the new firebrick calorimeter. This would be a senior, perhaps retired

person who would be available for occasional discussions. They also need available to them an advanced materials expert, who they have already identified. As the program proceeds, this person will become more and more central to the effort, and should be brought in as soon as possible. Other additions will probably become necessary as the project evolves, and NovaTech has indicated an awareness of this and is ready to recruit expertise as it is required. Their demonstrated ability to identify quickly and solve problems that emerge throughout the course of this project, and assign appropriate personnel to work tasks is critical. This team should head the design team meetings for further clarification of performance goals and design issues for work in progress. They are best qualified to lead the Phase I Test Cell effort.

Another recommended addition to personnel is a veteran government-trained configuration management person who would be utilized at 1/2 or 3/4 time to provide tight configuration and release control for procurement records, non-design drawings, and design drawings. Scientists and engineers typically rely on files for this activity, and do not record this information systematically or completely in their lab notebooks. Files can be lost, or accidentally destroyed.

Test Cell 2

The resource requirements for accomplishing the design and performance goals of Test Cell 2 present a slightly different kind of problem. As the basis for this task, there will already exist an energy cell that produces excess heat over hours of operation. Meeting the goal of 24 hours of continuous operation will require that the auxiliary process controllers be functional and can feed reactants to the energy reaction volume of the cell reliably and steadily. It remains to be discovered if the performance goal of 1 watt per cubic centimeter in the steady state is enough for self-sustaining operation.

At this stage, the power that is generated will now include the heat necessary to sustain the reaction. As a development device, there is no provision for extraction of useful energy; its entire energy production is going in to sustaining its operating temperature, or to ambient losses. The power generated will balance the heat loss to ambient in steady state operation. In later work, when the energy extraction/utilization device (such as an operating field system) is introduced, all the excess power won't be devoted to running the energy utilization device. Some power will be pulled back to sustain the transition reaction in the energy cell, and other energy will be put into electrical feedback for hydrolysis of water to generate hydrogen. In a commercial device, the system will be optimized for these factors. This fraction of energy used to sustain the cell and generate hydrogen may be interpreted as a fuel cost.

Personnel requirements may need to be adjusted for this task, based on the experienced gained in completing Test Cell 1, and this decision should be incorporated in the final Test Cell 1 design review.

Test Cell 3 and the Functional Prototype Energy Cell

Continually during these tasks the COMCO Commercialization Team must stay in contact with the Test Cell Design team concerning issues related to manufacturabilty: scaleup considerations/constraints and market information. During these stages, the Phase I development program must become increasingly interactive. Monthly design reviews are recommended to facilitate this process.

Also a continual dialogue between the engineers who are building the test cells and the COMCO person responsible for future interaction with OEMs must center around the expectations and requirements that must be met for a functional prototype energy cell. A first step in this direction is Jim Kendall's "Conceptual Characterization of HydroCatalysis Turbine Application Options" (Attachment E), and the detailed description of one of the ten options, "S-1 Radiant Recirculating Boiler" (Attachment F). Interaction and dialogue must be ongoing to ensure that the Phase I development work is focused on the requirements of the field prototype, and aligned with the constraints of the energy utilization device that it will be integrated into. *This dialogue must be continual, although it may require only a low level of effort to maintain. This should be part of the "initial product options" line 62.*

Already this activity has indicated that the commercial energy cell must be small to accommodate high power density on the inside and good heat transfer on the outside of the cell. Initial dimensional estimates are two to four cm in diameter and as long as possible (constrained by the kinetics of the transition reaction). The cells must operate at high temperatures (above 730 C), must maintain a vacuum inside, hold up to pressurized air or water outside (for some options), and have good heat conduction to the walls of the cell to facilitate its role in a heat exchanger. *This activity is already generating intellectual property for COMCO.* These integrated designs must be carefully documented and treated as sensitive trade secrets. Patentability of these designs for devices must be explored.

Feedback from this team must be factored into the Test Cell 2 and Test Cell 3 design objectives. *In particular the startup method for initiating the transition reaction in the test cells, once they are operating as part of a heat exchanger must be considered and planned for by Test Cell 3.* For example, initial heating of the energy cells might require that the pressure wall incorporate selective surface reflection capability. Other design requirements will develop in the course of this Phase I program. *Frequent interaction and discussion between the Test Cell Design teams and the commercialization team at COMCO will ensure that these issues are dealt with early on in the process and efficiently.*

At the Test Cell 3 / Functional Prototype Energy Cell demonstration stage, a cohesive life cycle operation paradigm needs to be outlined. The analysis can be concluded regarding what redesigns may be necessary to demonstrate number of cycles, number of closedowns and restarts will be necessary and expected. Early marketing studies would help identify these constraints such as how often an operator can afford to shutdown and restart the unit. This life cycle analysis is part of the continual comparison of design

specifications and customer needs that goes on for the entire Phase 1 effort as a background activity. The design after this one will generate a demonstrable shut-down and startup system for the energy cell, that occurs without human intervention. Also an estimate of how many cycles the unit will be required to execute, and its operating cost parameters can be determined towards the end of the Phase I planning period.

5. Provide comments regarding the viability of the projected schedule and recommendations for adjustments as appropriate. (Subtask 4)

COMCO has created an aggressive schedule, clearly so that commercialization can proceed as rapidly as possible. When it was determined that there was no cogent listing of performance goals for the test cells (milestone definition), I drafted a set that Jim Kendall and I worked on so they could be included in this report. As a result, the milestones were designed to be natural breaks in the course of work (slip/advance points). Kline-Anderson's independent calculation of the time required to reach each milestone matches up well with the original estimates in the COMCO schedule (Attachment B) after the Test Cell 1 milestone. We have recommended that personnel be augmented in several areas to meet the time goals. Once this performance milestone has been reached, the remainder of the schedule should be reviewed.

In Phase I development programs, such as this one, timeline milestones are often difficult to predict and to achieve owing to the uncertainties in the nature of development work. In this case, a radical design change to the energy cell has been adopted (aqueous phase to vapor phase). *Until Test Cell 1 operates successfully, no one can say how much the schedule may slip, because there isn't a test cell that works yet.* Given that the delivery date for the Test Cell 1 report is 12/3, the design team for this is in a very tough spot. This means the work must be completed by Thanksgiving. Even with augmenting the design team as discussed above, it would be reasonable to add 8 weeks to this task, to provide for procurement and implementation of the moly foil, calibration of the calorimeter, and enough process control ability to sustain the reaction for several hours. At least two more complete design/modification iterations are recommended. It could be approximately December 15 before NovaTech has a cell that they can begin to optimize for power density and duration of run time. During this period, they will have addressed several performance goals: 4, 5, 6 (see box). But will only be in a position to begin on 1, 2 and 3. Allowing an additional eight weeks for looking at 1, 2, and 3, puts the milestone for Test Cell 1 at Feb. 15. This is a best case scenario and assumes no new fundamental design problems emerge.

Performance Goals Test Cell 1

1. Show excess power operating over the noise level of the calorimeter (2% in the delta T measurement). Target excess power generation is 10%
2. Sustainable over hours (limit condensation/precipitation of catalyst and oxidation of tungsten filament)
3. Repeatable demonstration of excess power.
4. Controllable (controlled approach to excess power operating conditions and stable operation while generating target level of excess power)
5. Operating temperature 1000 to 1400 degrees C in the "hot zone" reaction volume as measured by the type C thermocouple.
6. Better understanding of cell insulation and refractory materials requirements.

This is all non-trivial laboratory work that has to be done when changing a basic apparatus, and even with augmenting the NovaTech staff, people who are accustomed to this sort of problem, it will take time. This is a significant schedule slip that is not avoidable.

Another likely place for a schedule slip to occur is if the redesign, management review and go-ahead takes more than the one day that is allocated for this task. To address this issue, and ensure that management is prepared, before the milestone date, for possible reallocation of resources, monthly design reviews are strongly recommended. These reviews should be on site, and conducted by COMCO's project manager and consultants that are selected for this purpose.

Because of the unavoidable uncertainty in the timeline for the milestones, it is important to create a concrete and clear understanding of the work in progress so that adjustments can be made prior to the milestone reviews. Monthly meetings are not too frequent at this stage. This uncertainty cannot be avoided, but its impact has been minimized by the formulation of specific design and performance goals for each step of the way, so that COMCO management can track work closely. This is a conventional way to handle the risk elements involved in Phase I development

As the degrees of risk are removed, it becomes more possible to make a concrete schedule that the COMCO team can stick to. But this actually is not realistic to expect before the first testing of the functional prototype unit itself. After that point, it is Kline-Anderson's experience that total schedule slippage approaches about 6% per year (this will be in Phase II).

6. Conclusions of a Technical Nature

For successful commercialization of this device, three goals must be met:

1. Increase in the power density that the cell will evolve: A reasonable goal for this is 100 to 150 kW/liter reaction volume. This is the comparable figure for boilers (reference Jim's report). It is estimated that a figure as low as 50 kW/liter will be economically viable

in a commercial unit. The economic viability cutoff power density depends on the features, benefits and costs of the final system.

2. *Controllability of the process:* An increased understanding of the interdependence of the operating parameters, their interdependence (degree of coupling), and instrumentation to control each must be put in place. This will result, ultimately in the basis for process control at the industrial (field test unit) level. Initially, this will be a simple on/off switch, or, ideally, a dial-type control that will vary the energy output of the cell.

3. *Prolonged operating duration at a self-sustaining power level:* The cells must continue to evolve energy after a starting procedure has been executed, and all energy input into the cell withdrawn.

The program is silent about several important concerns: Safety issues, such as storage and disposal of hydrogen gas have not been addressed. Possible rate limiting steps that may prevent the technology from being scaled to economic viability have not been questioned. For example, what chemical kinetics and process dynamics can be anticipated and provided for early in this program? Is the input current in a linear relationship with power evolved, and does that impact scaleup? Are there hidden dynamic characteristics of the process that will preclude scaleup? Does this reaction have a self-limiting aspect, and is there a competing quench reaction.

7. Off-Task Unsolicited Observations

Early marketing studies need to identify how many times in a week or month an operator can afford to restart his unit, and later cell designs must address this. This is the type of commercialization and scaleup issue that will come up more and more often throughout this work. Commercialization of this technology will be highly interactive owing to the nature of the process. Design reviews each month at all labs, are critical to this effort, and the report from the review should have the same intensity and focus that I have given one.

The unit first shown to outsiders, must operate without human intervention. It should be as easy to turn on as throwing one switch, and all safety gating should be in place. A self-sustaining run mode with appropriate shut off is required. To get the maximum financial return from a third party, this unit should not be shown to anyone before it is ready. COMCO cannot show a unit that doesn't work well and then claim to be able to fix it later.

I am concerned about the lack of formal peer review throughout the years Dr. Mills's theory has been published. There has been some peer review of an informal unpublished nature on Dr. Mills's theory. I am aware of Englemann's book review (noted in Technology Insights Technical Assessment). It is surprising that there is not one independently published paper that reports on the fundamental work in his theory, since it

was first published in 1989. It is provocative in its use of the Maxwell non-radiative boundary condition, and the use of the 3-dimensional Dirac delta function. For example, the interpretation of the Planck constant and the particle behavior of the electron is very interesting, and these ideas would seem to attract comment and dialogue from others. However, there seems to be a high threshold for serious consideration of the theory by the physics community. This may be due, in part, to the fact that the theory is contrary and revolutionary, and developed by an individual with unorthodox credentials.

COMCO is already generating intellectual property *now*.

In all aspects of the technology, but particularly in the scaleup into the commercialization of the technology, constant attention must be paid to intellectual property protection. This activity includes accurate documentation of trade secrets, filing of patents, international PCT filings, and all other aspects of intellectual property regime maintenance.

A COMCO Technical Advisory Board should be formed.

OEMs

An important part of the Phase I schedule involves discussions with OEMs. A focus of the Phase I work should be to prepare for these interactions from the beginning of the Test Cell work. We have expanded on the idea of a Test-Bed in the discussion of the Test Fixture above. The value of the Test Fixture, and the documentation that it creates about the energy generating process, is in these interactions with OEMs. *It is our opinion that work should continue in secret until an appropriate Demonstration Unit exists to show OEMs. This is not equivalent to Test Cell 2.*

The Demonstration Unit needs will be the first unit that anyone outside of COMCO, PacificCorp, HPC, or NovaTech is shown. This unit must operate without human intervention. It should be as easy to turn on as throwing a switch. All safety gating and release valves need to be in place, and it must start itself up independently, and convert itself over to the self-sustaining running mode automatically. This process should be evidenced to observers by easy to read meters. By throwing the "Off" switch, it must shut down in an appropriate and safe way. It is certainly acceptable to still have some engineering issues left, such as materials issues, and some scaleup. However, it is unwise to show a unit that doesn't work well (every time it is turned on), and add the assurance that it can be made reliable later.

Until this demonstration unit exists, we urge COMCO not to show intermediate results to anyone. Any disclosure of technology and progress contains risk for COMCO, and the potential benefit of the disclosure must be weighed against the risk. To get maximum return and involvement from an OEM, or other third party, an advanced level of development is advised. Our opinion of the "Conventional Wisdom" for return on investment during the commercialization stage is in the graph below. The amount an OEM will be willing to pay to get involved rises dramatically between a Sustainable Unit to a Stand Alone Functional Prototype. Return scales inversely with risk. On the graph

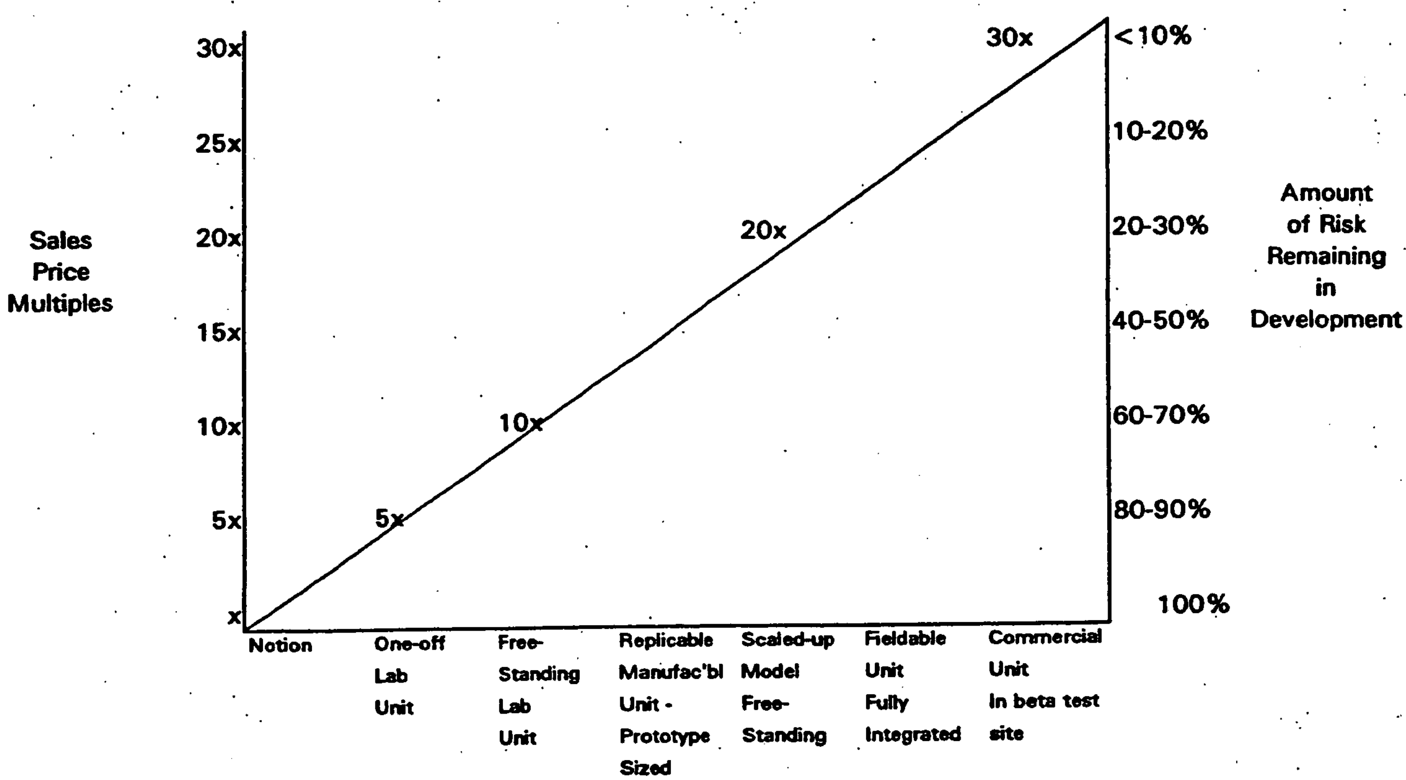
an idea, or "Notion", is worth "x" dollars at its inception; all the risk for getting the product based on that idea to the market remains at 100%. As commercialization proceeds and risk is removed from the investment, the number of dollars that an investor is willing to pay increases. We have depicted this by scaling the value (x) that the original notion was worth. For example, once a Free-Standing Lab Unit exists, an investor would be expected to pay 10 times the amount of the value of the invention at the "Notion" or idea stage. As risk is removed from the venture due to the progress of the commercialization work (move right along the x-axis), then at the stage of a Commercial Unit in Beta Test the only risk remaining is the financial risk of the final step to the market (labeled <10%). There is a dramatic increase in value from the One-Off Lab Unit, to the Scaled-up Free Standing Model. COMCO can maximize its investment value by progressing as far along the commercialization phase as possible.

Dr. Mills's desire to talk to OEMs too early is a risky approach and in fact goes against the conventional wisdom that you keep people away as long as you possibly can, and reduce the risks as far as you can, to realize the maximum financial return from your investment. If OEMs see a unit that is not working well, sustainably, consistently, or can't be turned on remotely with a safe shut-down, financial possibilities will be diminished.

COMCO Leadership

Finally, the role of strong leadership provided by COMCO cannot be overstated. The success of this Phase I effort depends on a high level of interactively, communication, and cooperation between PacifiCorp, COMCO, HPC and NovaTech. This can be achieved through regularly scheduled conference calls, e-mail, and monthly design review meetings at each site conducted by COMCO's project manager and select consultants selects. To perform on this aggressive schedule, no delays due to miscommunication can be permitted.

"Conventional Wisdom" Regarding Sales Price of An Opportunity (SP) to an OEM.



Attachment A

Commitment to Commercialization Investment
Phases I - IV.   (Technology Insights)

A

10. Phase Structure/Commitment to Commercialization Investment

The following phases will overlap in time:

- Phase I - Functional Prototype (~2 years)

  Development and evolution of energy cells to address identified initial device application(s). Integration of hydrocatalysis energy cells with one or more energy utilization devices (e.g., gas turbine) for operation in a shop environment. Unit operation and modifications to identify and resolve resulting technical issues.

- Phase II - Commercial Prototype Engineering/Fabrication (~1-2 years)

  Design, supporting subcomponent testing (as necessary and practical), fabrication and factory acceptance testing of energy utilization devices for field operation in demonstration projects.

- Phase III - Demonstration/Commercial Unit Engineering (~1-2 years)

  Operation of prototypes, analysis of operating data, revisions to prototype design to establish final commercial design plus unit cost and reliability projections.

- Phase IV - Commercial Production Infrastructure (~1-2 years)

  Manufacturing engineering, retooling, quality assurance program, and production and factory acceptance testing of initial production units.

Attachment B

HydroCatalysis Project Phase I Schedule dated 9/24/96. (Technology Insights)

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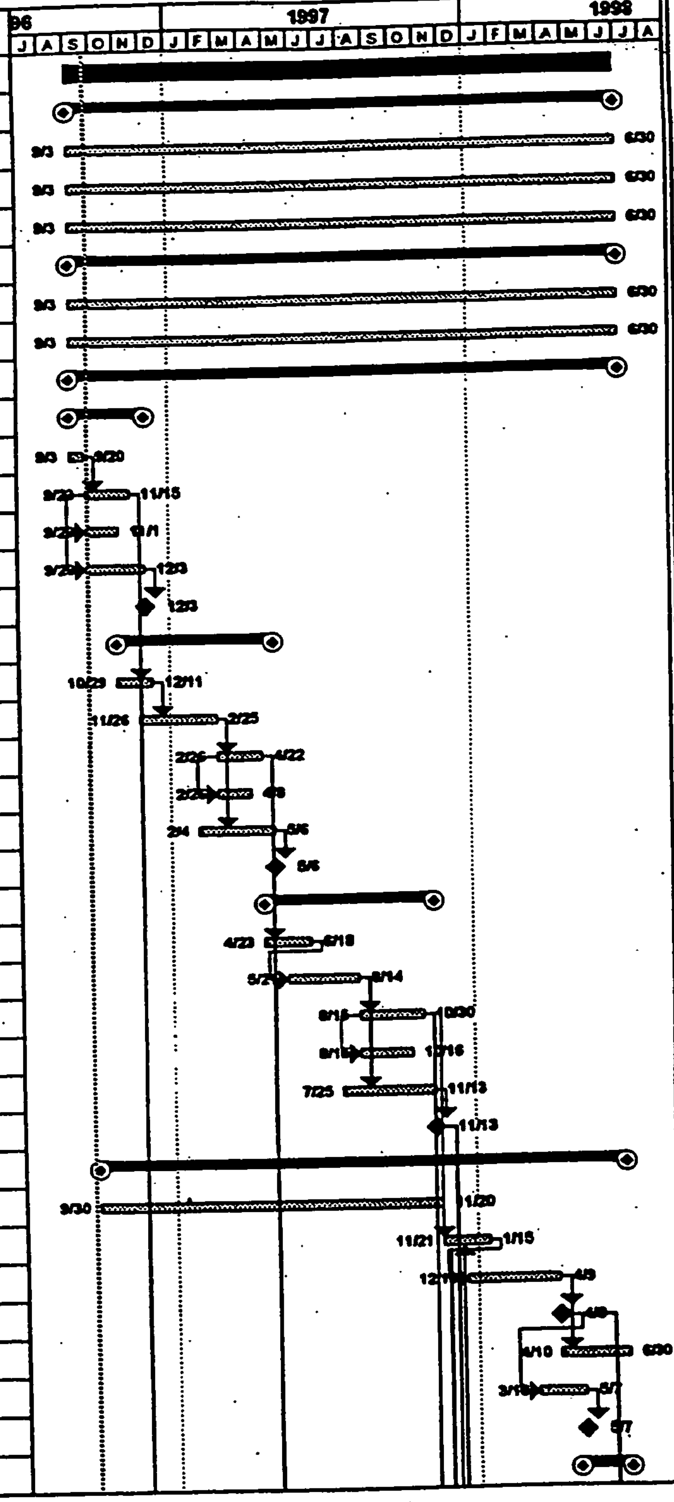
HydroCatalysis Project

ID	Task Name	Duration	Predecessors
1	**HPC**	468d	
2	Administration	468d	
3	Financial	468d	
4	Contracts/Legal	468d	
5	Patents	468d	
6	Research	468d	
7	Concept Development	468d	
8	Theory Validation	468d	
9	Engineering	468d	
10	Test Cell 1	64d	
11	Procure/Fab	14d	
12	Operation	40d	11
13	Modifications	30d	12SS
14	Analysis/Doc.	50d	13SS
15	*TC 1 Report*	*0d*	*14*
16	Test Cell 2	130d	
17	Design	30d	12FS-14d
18	Procure/Fab	60d	17FS-10d
19	Operation	40d	18
20	Modifications	30d	19SS
21	Analysis/Doc.	65d	18FS-15d
22	*TC 2 Report*	*0d*	*21*
23	Test Cell 3	145d	
24	Design	40d	19
25	Procure/Fab	60d	24FS-20d
26	Operation	55d	25
27	Modifications	45d	26SS
28	Analysis/Doc.	80d	25FS-15d
29	*TC 3 Report*	*0d*	*28*
30	Func. Proto. Unit ECell	449d	
31	FP Unit Defn.	291d	
32	FPU ECell Desn.	40d	68,26
33	FPU ECell Fab.	80d	32FS-20d
34	*Ship FPU ECell*	*0d*	*33*
35	ECell Integr./Op.	58d	33
36	FPU ECell Doc.	40d	34FS-20d
37	*FPU ECell Rpt.*	*0d*	*36*
38	Prototype Unit ECell	43d	

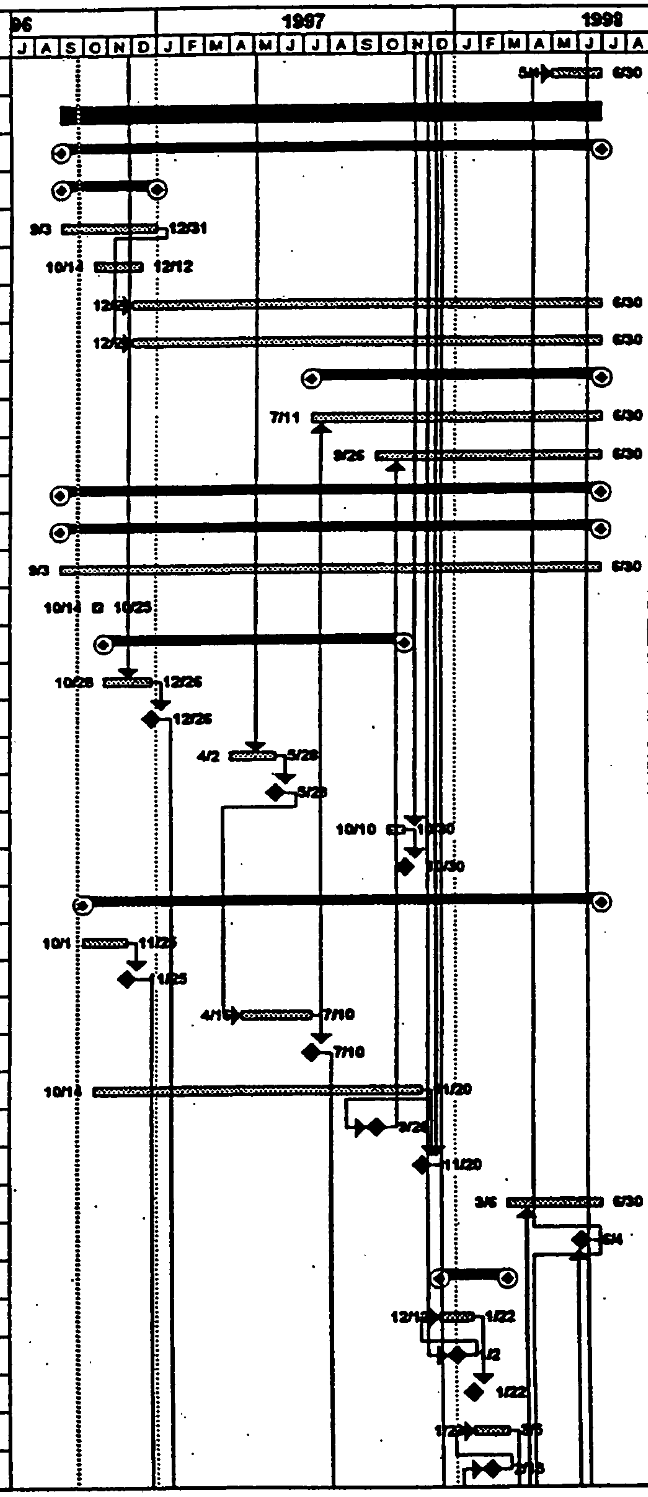


Project: HCat1.MPP
Date: Tue 9/24/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

HydroCatalysis Project

ID	Task Name	Duration	Predecessors
39	Prot. Unit Input	43d	70FS-25d
40	COMCO	468d	
41	Administration	468d	
42	COMCO Formation	82d	
43	Coordination	82d	
44	Comm'l Strategy Study	42d	
45	Financial	406d	43FS-20d
46	Contracts/Legal	406d	43FS-20d
47	Intellectual Property Developme	253d	
48	Training/Engg. Oversight	253d	64
49	Patent Applications	198d	67
50	Applications Engineering	468d	
51	Project Management	468d	
52	Initial Prototype Project	468d	
53	Resource/Sched Review	10d	
54	Process Characterization	256d	
55	Inital ProcChar	40d	12FS-15d
56	*PC Rpt Rev.0*	*0d*	55
57	Update ProcChar	40d	19FS-15d
58	*PC Rpt Rev.1*	*0d*	57
59	Update ProcChar	15d	26FS-15d
60	*PC Rpt Rev.2*	*0d*	59
61	Product Characterization	448d	
62	Initial Prod. Options	40d	
63	*PO Rpt. Rev.0*	*0d*	62
64	Update Prod. Options	60d	58FS-30d
65	*PO Rpt. Rev.1*	*0d*	64
66	Func. Proto. Unit Defn.	281d	
67	*FPU Func. Guidelines*	*0d*	*66FS-40d*
68	*FPU Selection*	*0d*	*66,29FS+5d*
69	Prot. Unit Defn.	83d	77
70	*PU Func. Guidelines*	*0d*	*80FS+20d*
71	Design Reviews	60d	
72	FPU ECell Rev.	30d	73FS-15d
73	*FPU ECell DR Mtg.*	*0d*	*32FS-10d*
74	*FPU ECell DR Rpt.*	*0d*	72
75	FPU EUD Rev.	30d	76FS-15d
76	*FPU EUD DR Mtg.*	*0d*	*102FS-10d*

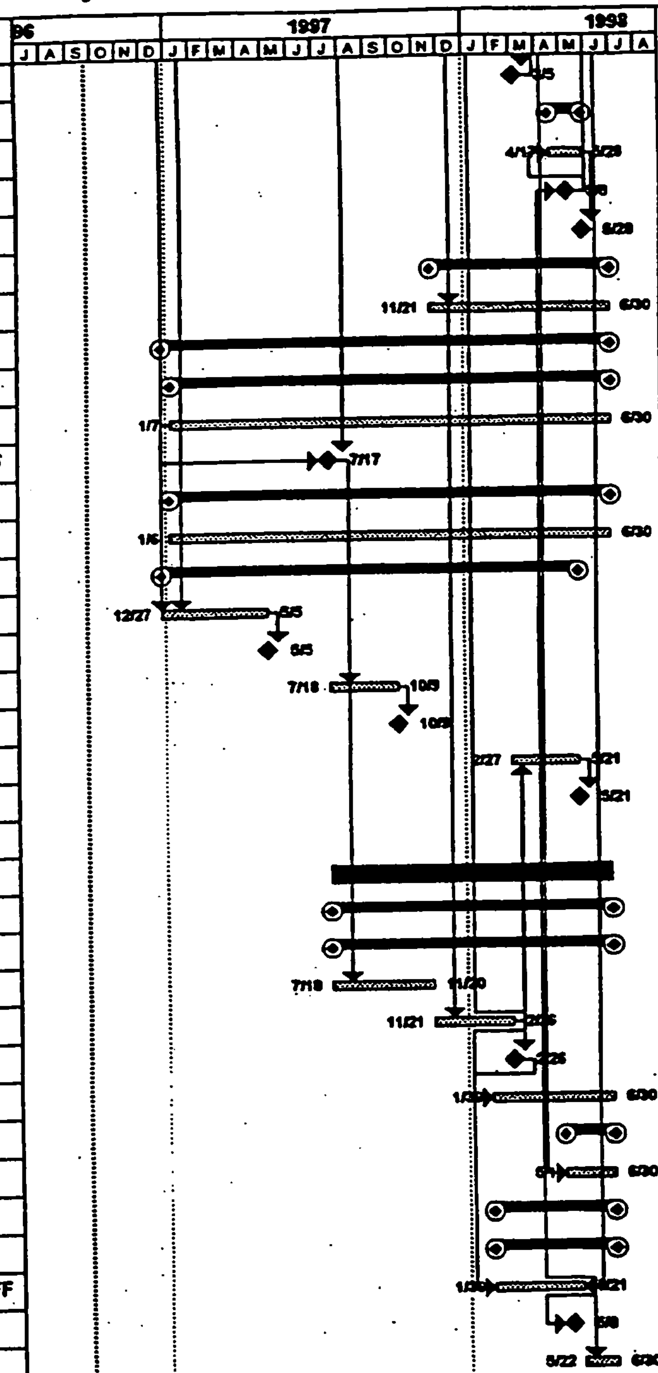


Project: HCat1.MPP
Date: Tue 9/24/96

Task
Progress
Milestone
Summary
Rolled Up Task
Rolled Up Milestone
Rolled Up Progress

HydroCatalysis Project

ID	Task Name	Duration	Predecessors
77	*FPU EUD DR Rpt.*	*0d*	75
78	**Readiness Reviews**	**30d**	
79	FPU Opnl RR	30d	80FS-15d
80	*FPU ORR Mtg.*	*0d*	*109FS-10d*
81	*FPU ORR Rpt.*	*0d*	*79*
82	**New Concepts**	**158d**	
83	Concept Development	158d	68
84	**Marketing**	**389d**	
85	**Vendor/OEM Interactions**	**383d**	
86	Vendor/OEM Contacts	383d	
87	*Select Lead V/OEM*	*0d*	*86SS+60d,65FS*
88	**End User Interactions**	**384d**	
89	Prospective Participants	384d	
90	**Business Plans**	**361d**	
91	Initial Bsns Plan	90d	56,63
92	*Bsns Plan Rev.0*	*0d*	*91*
93	Update Bsns Plan	60d	87
94	*Bsns Plan Rev.1*	*0d*	*93*
95	Update Bsns Plan	60d	102
96	*Bsns Plan Rev.2*	*0d*	*95*
97			
98	**LEAD VENDOR/OEM**	**248d**	
99	**Engineering**	**248d**	
100	**Func. Proto. Unit**	**248d**	
101	Func. Proto. Unit Input	90d	87
102	FPU EUD Design	70d	68
103	*FPU Design Report*	*0d*	*102*
104	FPU Fab/Op Support	108d	103FS-20d
105	**Prototype Unit**	**43d**	
106	Prot. Unit Input	43d	70FS-25d
107	**Manufacturing**	**108d**	
108	**Func. Proto. Unit**	**108d**	
109	FPU Fab/Installation	80d	102FS-20d,34FF
110	*FPU Operating Manual*	*0d*	*109FS-10d*
111	FPU Operation	28d	109



Project: HCat1.MPP
Date: Tue 9/24/96

Task		Rolled Up Task	
Progress		Rolled Up Milestone	◇
Milestone	◆	Rolled Up Progress	
Summary			

9 **Engineering**
The task groups labeled Test Cell 1, 2 and 3 each represent a series of tests conducted with one or more devices of similar construction. The design tasks of the test cell series include design of auxiliary, control, and data gathering and analysis systems as needed to conduct the full scope of the test. The procurement/fabrication tasks include the assembly, calibration and initial shakedown operation of the equipment. The analysis/documentation tasks include initial definition and necessary adjustments of the test matrix, as well as data collection, integration, analysis and documentation in a test report.

10 **Test Cell 1**
A device whose design and fabrication is currently in progress at NovaTech under contract to HPC. Quartz tube in fire brick, designed to operate at 700 C,

16 **Test Cell 2**
A device currently envisioned to utilize a stainless steel outer container with internal ceramic insulation and designed to operate at 2000 C in the reaction zone.

23 **Test Cell 3**
A scaleup of the test cell 2 device designed for comparable operating temperature with a geometry evolving toward a heat exhanger configuration for the functional prototype unit energy cell.

30 **Func. Proto. Unit ECell**
The functional prototype unit includes an energy cell plus its auxiliaries and controls, in conjunction with an energy utilization device, as well as necessary instrumentation, data gathering and analysis equipment. The unit would be designed for operation in a controlled shop environment, with emphasis on understanding and resolving issues associated with the integration of an energy cell and energy utilization device over the range of expected operating conditions. Auxiliary and control systems for the energy cell would not necessarily be physically integrated with those of the energy utilization device.

54 **Process Characterization**
Interactions with HPC/NovaTech regarding cell design and operating experience to characterize the process as it relates to selection of an energy utilization device for initial development (e.g., temperature, pressure, power density, heat transfer and dynamic response characteristics).

61 **Product Characterization**
Integrating results from the process characterization and product options identification activities to develop functional guidelines for the initial unit, leading to selection of an initial unit concept for detailed design, fabrication and operation as a functional prototype. Subsequent integration of data from energy cell development and functional prototype experience to guide the development of a prototype unit.

82 **New Concepts**
Identification and development of new application concepts tailored to the characteristics of the HydroCatalysis process.

85 **Vendor/OEM Interactions**
Contacts with vendor/OEM organizations considered candidates for the lead vendor/OEM, leading to establishment of a contractual relationship to design, fabricate and operate the functional prototype unit.

88 **End User Interactions**
Support of PHI and/or HPC initiatives to involve additional end users (e.g., utilities, IPP companies) in COMCO, communications with COMCO owners, and coordination of the participation of representatives from COMCO owners in design reviews, operational readiness reviews, etc.

90 **Business Plans**
Development and documentation of long term plans and strategies for COMCO structure and operations.

100 **Func. Proto. Unit**
The functional prototype unit includes an energy cell plus its auxiliaries and controls, in conjunction with an energy utilization device, as well as necessary instrumentation, data gathering and analysis equipment. The unit would be designed for operation in a controlled shop environment, with emphasis on understanding and resolving issues associated with the integration of an energy cell and energy utilization device over the range of expected operating conditions. Auxiliary and control systems for the energy cell would not necessarily be physically integrated with those of the energy utilization device.

102 **FPU EUD Design**
EUD is energy utilization device (e.g., gas turbine, process heat supply), assumed to be a modification of an existing design to accommodate the HydroCatalysis energy cell.

105 **Prototype Unit**
The prototype unit would draw upon earlier experience to produce an integrated unit for field operation in one or more demonstration projects.

Attachment C

HydroCatalysis Project
Phase I - Functional Prototype
Energy Cell Development

The following material provides a definition of the design and performance objectives of an evolving series of HydroCatalysis energy cells leading to an energy cell unit to be integrated with an energy utilization device for the functional prototype unit. Titles refer to task summary entries in the HydroCatalysis project integrated schedule.

Engineering:

The task groups labeled Test Cell 1, 2 and 3 each represent a series of hardware and process design and engineering tests conducted with the vapor phase hydrino power cell (energy cell) that has been developed in collaboration at the HPC and NovaTech labs (note - current expectations are that NovaTech personnel performing the work will move within HPC or COMCO). The milestone reports for each test cell represent design evolution and engineering performance milestones in the evolution of this concept, not different concepts for the embodiment (physical implementation) of the hydrino power cell invention itself.

The design tasks of the test cell series include design of auxiliary, control, and data gathering and analysis systems as needed to conduct the full scope of the test. The procurement/fabrication tasks include the assembly, calibration and initial shakedown operation of the equipment. The analysis/documentation tasks include initial definition and necessary adjustments of the test matrix, as well as data collection, integration, analysis and documentation in a test report.

Test Cell 1

Objective: To achieve a design of a cell that will operate repeatedly and controllably, and use as a basis to formulate a strategy for subsequent cell development.

Design Goals:

- Independently control catalyst vapor partial pressure (utilize an externally heated reservoir, no high temperature seals)
- Utilize a flowing hydrogen cell (prevent "fuel" starvation)

- Overcome the thermal limitations of previous vessels & insulation (keep stainless steel vessel sufficiently cool, but keep stainless steel vessel hot enough so catalyst precipitation is reduced)
- Design and fabricate a relatively inexpensive test bed (allow for high surface area tungsten foams or powders, allow for various catalysts, investigate other materials, investigate different operating scenarios (T, P, flow, etc.))

Performance Goals:

- Show excess power operating over the noise level of the calorimeter (2% in the delta T measurement). Target excess power generation is 10%
- Sustainable over hours (limit condensation/precipitation of catalyst and oxidation of tungsten filament)
- Repeatable demonstration of excess power
- Controllable (controlled approach to excess power operating conditions and stable operation while generating target level of excess power)
- Operating temperature (other than the filament) 1000 to 1400 degrees C in the "hot zone" reaction volume as measured by the type C thermocouple
- Better understanding of cell insulation and refractory materials requirements

Optimal operating parameters expected to be: reaction zone partial pressures of 2 torr potassium iodode or 0.2 torr Rubidium iodide, 200 millitorr hydrogen, as high an operating temperature as possible, power density will be optimized by adjustment of partial pressures and temperatures within the limits of the device. Three Test Cell 1 devices have been fabricated: TC1A for operation by NovaTech directed toward the above objectives, TC1B and TC1C for operation by HPC to improve the understanding of the process by variation of key parameters. Test Cells TC1B and TC1C will have a partial Data Acquisition System.

Test Cell 2

Objective: Self-Sustained Operation (Long term (24 hour) operation without electrical input to the filament while maintaining reaction zone temperatures sufficient to support molecular hydrogen dissociation).

Design Goals:

- Higher temperature capability (eliminate oxide insulation through use of multi-layer insulation)

- Better vacuum system (reduce bake-out times required, improve quality of bake-out)
- Automated Data Acquisition System (DAS)
- Improved catalyst pressure control
- Attempt to eliminate catalyst "loss"
- Instrumentation for optimization of operating parameters (prep for scaleup)
- Delta-T thermocouples at faster responding locations
- Greater range in power supply/controllable constant power source
- Design and fabricate a relatively inexpensive test bed for operation at higher temperatures than Test Cell 1 (allow for high surface area tungsten foams or powders, allow for various catalysts, investigate other materials, investigate different operating scenarios (T, P, flow, etc.))

Performance Goals:

- Reliable and repeatable startup and operation in a self-sustained mode for periods in excess of 24 hours
- Quantitative understanding of power production as a function of key operating parameters
- Average power density in the reaction zone volume greater than 1 watt per cubic centimeter in steady state
- Reliable operation of supporting auxiliary systems
- Centerline temperature operation in the range 1300 - 2000 °°C

Test Cell 3:

Objective: An engineering redesign of the self-sustaining Test Cell 2 device, designed for comparable operating temperature with a geometry evolving toward a heat exchanger configuration for the functional prototype unit energy cell.

Design Goals

- Designed with advanced refractory materials, where required, from the outset
- Designed to eliminate net catalyst loss during normal operation, including slow reactions of catalyst with cell contents and vessel
- Provision for fabrication of multiple devices of varying length to investigate fuel and catalyst transport limits, with provision for axial data on performance for longer cells
- Provision for cell heat loss characteristics to support both initial heatup power requirements and heat transfer requirements of steady state operation beyond goal power densities
- Provision for parallel operation of two energy cell units serviced by a common power supply, hydrogen supply, catalyst supply and vacuum system

- The materials and design of this cell will provide the basis for study of commercial scaleup in terms of materials choice for function and price of the Functional Prototype Unit Energy Cell
- Analytical projection of sufficient operating lifetime for key materials
- Provision for removal of reaction products or foreign gases during long term operation

Performance Goals

- Reliable and repeatable startup and operation in a self-sustained mode
- Operation of an energy cell in a self-sustained mode for a period in excess of one week
- Average power density in the reaction zone volume greater than 10 watts per cubic centimeter in steady state
- Stable startup and operation of two or more energy cells supported by a common power supply, hydrogen supply, catalyst supply and vacuum system
- Quantitative data on the effect of energy cell length on performance
- Quantitative data supporting the key materials design lifetime analysis

Functional Prototype Unit Energy Cell

Objective: Parallel energy cells, as well as necessary instrumentation, data gathering and analysis equipment designed and fabricated for operation in conjunction with an energy utilization device. The resulting functional prototype unit (combination of hydrocatalysis energy cell unit and energy utilization device) will be designed for operation in a controlled shop environment, with emphasis on understanding and resolving issues associated with the integration of an energy cell and energy utilization device over the range of expected operating conditions. This program may be under the auspices and largely funded by an OEM.

Design Goals:

- An energy cell unit comprised of multiple energy cells operating in parallel and serviced by a common power supply, hydrogen supply, catalyst supply and vacuum system
- Provisions for automated startup and operation of the energy cell unit meeting the environmental and control requirements of the energy utilization device while operating in a controlled shop environment (Auxiliary and control systems for the energy cell would not necessarily be physically integrated with those of the energy utilization device)
- Energy cell unit capability (startup, dynamic response, power production, lifetime) as required to support the energy utilization device over a range of conditions covering the planned test matrix
- OEM input

Performance Goals:

- Reliable and repeatable startup and operation
- Power production consistent with the design operating range of the energy utilization device
- Stable operation and dynamic response characteristics consistent with the requirements of the energy utilization device
- Satisfactory operation over the conditions of the planned test matrix
- OEM input

Attachment D

List of Documents received by Kline-Anderson Inc. as background material from HPC and Technology Insights.

HPC:
Confidential Business Summary
Confidential Short Business Summary
"Fractional Quantum Energy Levels of Hydrogen" Fusion Technology, Nov. 1995.
Confidential Paper "Fractional Quantum Energy Levels of Hydrogen Representative Recent Results Prepared For Kline Anderson"
Book review by Dr. Reinhart Engelmann
Confidential Company Presentation
Confidential Protocols:

- Search For the Mills Hydrino: An Extreme UV Spectroscopy Proposal
- Measurement of Excess Heat From Hydrino Production
- Protocol For the Synthesis of Dihydrino Molecules
- Protocol For Heat Measurements With the High Temperature Vapor Phase Cell
- Protocol for Heat Measurements With the AtMar Glass Lamp
- Protocol for Calvet Measurements of the High Temperature Vapor Phase Cell
- Carbon XPS Protocol
- Gas Phase Hydrocatalysis: Proof of Principal Potassium Carbonate Coated Nickel Hydride Experiments

One Kilowatt Electric Prototype Proposal

Technology Insights:
HydroCatalysis Technical Assessment, August 30, 1996

Attachment E

"Conceptual characterization of HydroCatalysis Turbine Application Options" (Technology Insights).

COMCO Technical Support Workscope

Conceptual Characterization of HydroCatalysis Turbine Application Options

1.0 Objective

Identify steam and gas turbine options for power generation using the HydroCatalysis process and characterize each option in terms of conceptual configuration, environmental conditions imposed on a HydroCatalysis energy cell, existing experience and precedence, and system design and development issues. Select one or more preferred options for continued evolution in concert with the ongoing development of the energy cells.

2.0 Background

The initial application of the HydroCatalysis process, to be developed jointly by COMCO and BlackLight Power, is anticipated to be for power generation utilizing either a steam or gas turbine. Since the fuel cost of the HydroCatalysis process is anticipated to be small, corresponding to the amortized capital and operation costs associated with production of hydrogen from water, achieving high efficiency is of lesser importance than for conventional power generation technologies. This will reduce the importance of efficiency in the optimization of the overall unit design primarily to its effect on capital cost. The options identified for further definition are intended to span the range of likely approaches for power generation, with expected significant variations in demands on the development of the HydroCatalysis energy cell, in design and development requirements for the power conversion equipment, and in projected commercial unit capital costs. The overall objective is to narrow the field of options being considered with the intent of arriving at one or more functional prototype units for near term development.

3.0 Options to be Addressed

The system configuration options listed below will be considered along with additional options which may be identified in the course of the work. Initial conceptual information is provided in an appendix to this document as a starting point for each configuration and to illustrate the approach to be taken and the information to be developed.

3.1 Steam Turbine

For the steam turbine options, the interface with the energy cell will be either directly or indirectly with a steam boiler. In light of the decreased importance of efficiency, lower pressure saturated or moderately superheated steam, similar to the

steam conditions in commercial water reactor power plants may be appropriate. The following steam turbine options, as defined in the appendix, will be considered.

S-1 Radiant Recirculating Boiler

S-2 Radiant Once-Through Boiler

S-3 Natural Convection Recirculating Boiler

S-4 Forced Convection Once-Through Boiler

S-5 Forced Convection Intermediate Loop Boiler

3.2 Gas Turbine

Gas turbine options will include open and closed cycles, with cycle efficiency to be addressed in a manner consistent with the approach for the steam cycles. The following gas turbine options, as defined in the appendix, will be considered.

G-1 Radiant Open Cycle

G-2 Forced Convection Open Cycle

G-3 Forced Convection Intermediate Loop Open Cycle

G-4 Radiant Closed Cycle

G-5 Forced Convection Closed Cycle

4.0 Scope of Activities

This effort will encompass the activities defined below.

4.1 Option Characterization

Using the material in the appendix as a starting point, characterize the options in sufficient detail to support the selection of one or more preferred options for further development as candidate(s) for a functional prototype. The following information will be developed for each option:

- **Concept Strengths** - Expand and quantify the list of positive attributes identified in the appendix
- **Design Issues** - Expand and quantify the list of design issues identified in the appendix
- **Energy Cell Environment** - Quantify the energy cell environmental parameters identified in the appendix (with additional parameters if appropriate)

- **Development Requirements** - Identify the scope of activities for development of the functional prototype and commercialization of the concept
- **Market Potential** - Identify the range of products (size range, applications) and estimate the unit costs for volume production

The degree of detail and level of confidence in the results will be consistent among the options addressed and sufficient to support a comparison for the purpose of narrowing the field of options under consideration. The results will be documented in a product options report in a format consistent with the information in the appendix, with additional considerations noted above included.

4.2 Preferred Option(s) Selection

Using the results developed by the work defined in the previous section, a meeting will be held to select the preferred option or options for further definition and iteration with energy cell development as a basis for the functional prototype unit.

4.3 Preferred Option(s) Development

Continue the design and characterization of the selected option(s) in support of the functional prototype unit development and COMCO commercialization plans.

Appendix - Turbine Application Options Conceptual Summary

Steam and gas turbine power conversion system options for the application of the HydroCatalysis process are defined in summary form on the following pages. This information is provided as a starting point for an effort to further develop and characterize the options, leading to the selection of one or more preferred concepts for further development. The options as defined here may be modified or more attractive options developed in the course of the work. The following options are identified:

- S-1 Radiant Recirculating Boiler
- S-2 Radiant Once-Through Boiler
- S-3 Natural Convection Recirculating Boiler
- S-4 Forced Convection Once-Through Boiler
- S-5 Forced Convection Intermediate Loop Boiler
- G-1 Radiant Open Cycle
- G-2 Forced Convection Open Cycle
- G-3 Forced Convection Intermediate Loop Open Cycle
- G-4 Radiant Closed Cycle
- G-5 Forced Convection Closed Cycle

The concept strengths and design issues are intended to address considerations external to the energy cells as well as demands placed on the design and operation of the energy cells. It is assumed that all of the options will be based on a self-sustaining energy cell design (i.e., no electric power input required in the power operation range). Based on current understanding of the HydroCatalysis process, this is further assumed to require the achievement of elevated temperature conditions (e.g., > 1500°C) in the reaction zone of the energy cell. Thus the need for high temperature materials and the resulting design issues for the energy cells is considered applicable for all of the options.

Option S-1 Radiant Recirculating Boiler

Precedents

ABB/Combustion Engineering, Foster Wheeler oil, gas and coal fired steam boilers.

Summary Description

A bank of cylindrical HydroCatalysis energy cells is positioned adjacent to a bank of boiler tubes inside an insulated container with a reflective inner surface. A movable mirror lattice between the energy cells and boiler tubes is used to control heat transfer from the energy cells during startup and power operation. The boiler circuit is a natural convection recirculating loop with a steam drum containing steam separation equipment to meet the minimum inlet steam quality requirements of the turbine.

Concept Strengths

1. Low external pressure on energy cells
2. No flow induced structural loads on energy cells
3. Control of energy cell heat losses during startup
4. Boiler tube temperature relatively constant over the tube length and over the load range

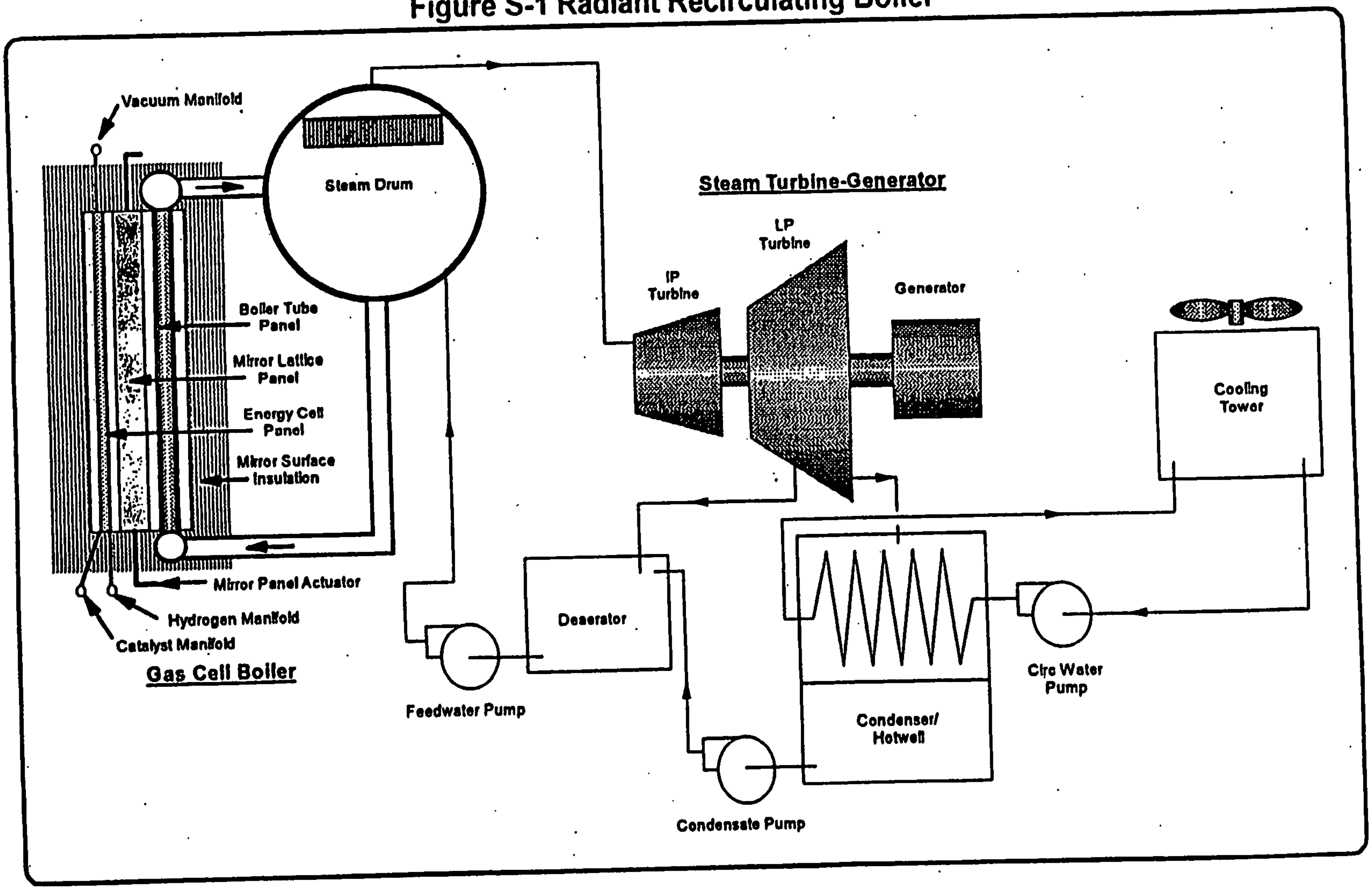
Design Issues

1. Accommodation of thermal expansion
2. Energy cell temperature variation characteristics over the load range
3. Radiant panel heat flux - size requirements

Energy Cell Environment

1. Temperature distribution and operating range
2. Startup and control requirements

Figure S-1 Radiant Recirculating Boiler



Option S-2 Radiant Once-Through Boiler

Precedents

Babcock & Wilcox oil, gas and coal fired steam boilers.

Summary Description

A bank of cylindrical HydroCatalysis energy cells is positioned adjacent to a bank of boiler tubes inside an insulated container with a reflective inner surface. A movable mirror lattice between the energy cells and boiler tubes is used to control heat transfer from the energy cells during startup and power operation. The boiler circuit is a forced convection once-through system producing superheated steam.

Concept Strengths

1. Low external pressure on energy cells
2. No flow induced structural loads on energy cells
3. Control of energy cell heat losses during startup

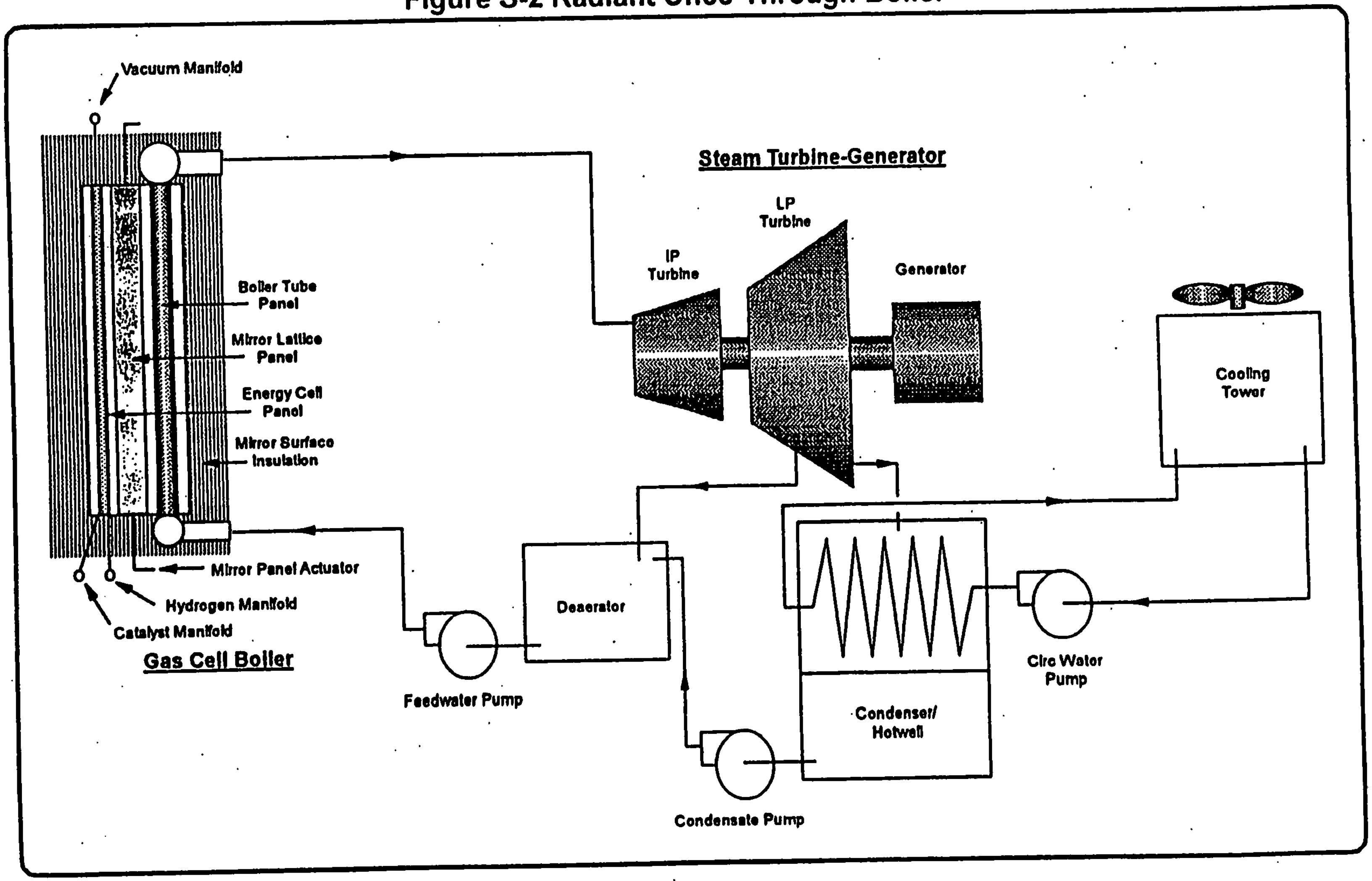
Design Issues

1. Accommodation of thermal expansion
2. Energy cell temperature variation characteristics axially and over the load range
3. Radiant panel heat flux - size requirements
4. Boiler tube stability
5. Boiler startup and dynamic control requirements

Energy Cell Environment

1. Temperature distribution and operating range
2. Startup and control requirements

Figure S-2 Radiant Once-Through Boiler



Option S-3 Natural Convection Recirculating Boiler

Precedents

General Electric Boiling Water Reactors, U-tube steam generators for Westinghouse and ABB/Combustion Engineering Pressurized Water Reactors.

Summary Description

The energy cells are placed in tubes projecting into the boiler vessel in a bayonet configuration with external support grids. Recirculating water from the swirl vane separator and steam dryer mix with incoming feedwater, resulting in moderate subcooling at the bottom. The energy cell surface conditions are liquid convection in the bottom region, changing to nucleate boiling over the majority of the cell length.

Concept Strengths

1. High energy cell surface heat flux capability
2. Stable cell surface temperature and heat removal characteristics
3. Energy cell surface temperature relatively constant over the tube length and over the load range

Design Issues

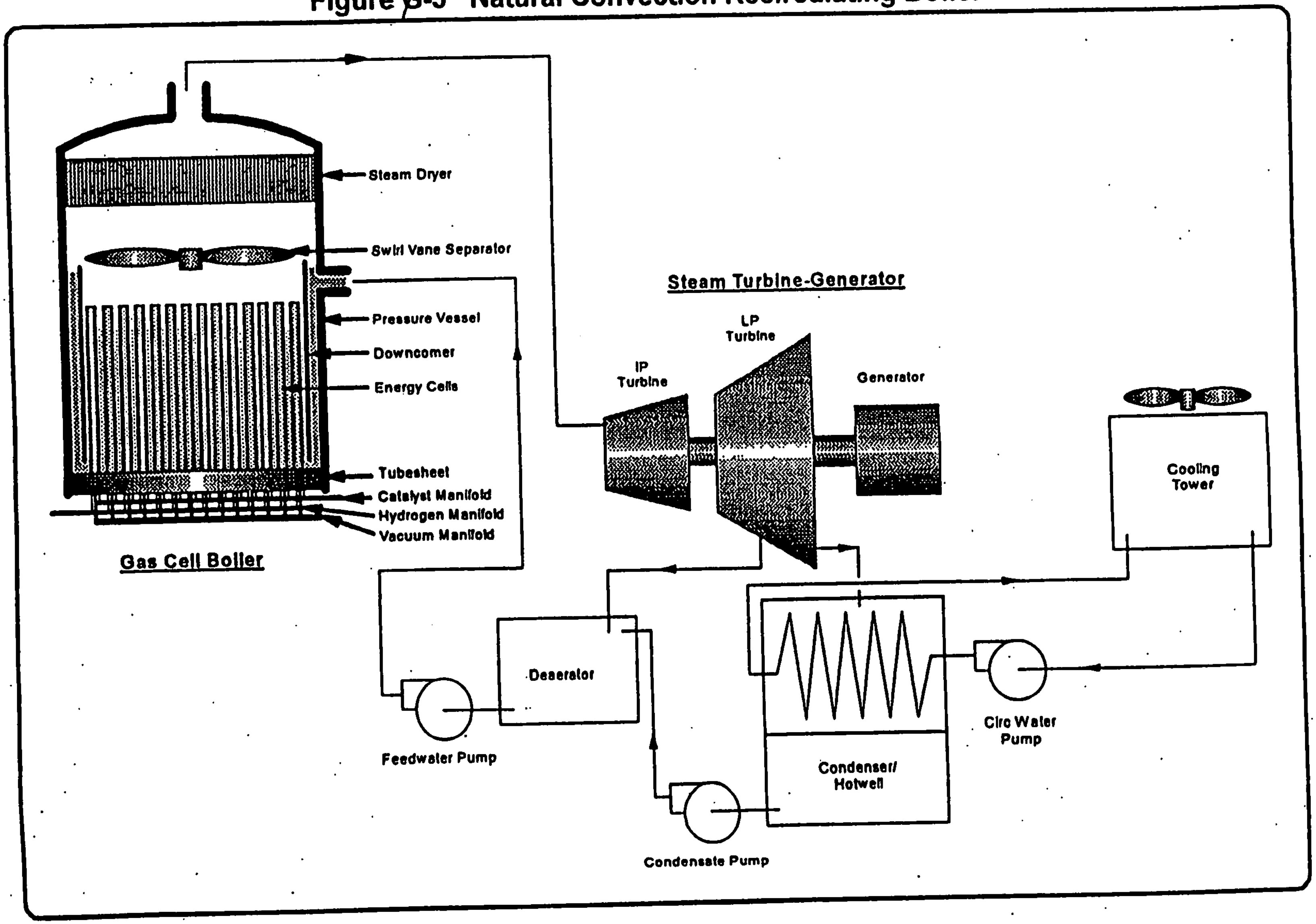
1. Achieving self-sustaining energy cell temperature conditions during startup
2. Accommodation of energy cell internal thermal expansion
3. Single-ended access for hydrogen, catalyst and vacuum manifolds

Energy Cell Environment

1. External pressure range
2. Temperature distribution and operating range
3. Flowrates and flow induced loads
4. Startup and control requirements

* PHI Confidential Information - Work Product for Hire Property of PHI

Figure 5-3 Natural Convection Recirculating Boiler



Option S-4 Forced Convection Once-Through Boiler

Precedents

Babcock & Wilcox steam generators for Pressurized Water Reactors.

Summary Description

The energy cells are placed in tubes projecting through the boiler vessel tubesheets with tube support grids on the shell side. Feedwater enters the bottom of the vessel on the shell side and exits as moderately superheated steam (sufficient to preclude moisture carryover from dynamic variations or nonuniform spatial effects. The energy cell surface conditions are single phase liquid convection in the bottom region, changing sequentially to nucleate boiling, film boiling and single phase vapor convection at the top.

Concept Strengths

1. Simplicity of boiler internals
2. High energy cell surface heat flux capability in the single phase liquid and nucleate boiling zones

Design Issues

1. Accommodation of thermal expansion in energy cells and between tube bundle and vessel (may require bellows or sliding seals)
2. Achieving self-sustaining energy cell temperature conditions during startup
2. Energy cell temperature response characteristics over the load range
3. Axial movement of heat transfer zones during load changes

Energy Cell Environment

1. External pressure range
2. Temperature distribution and operating range
3. Flowrates and flow induced loads
4. Startup and control requirements

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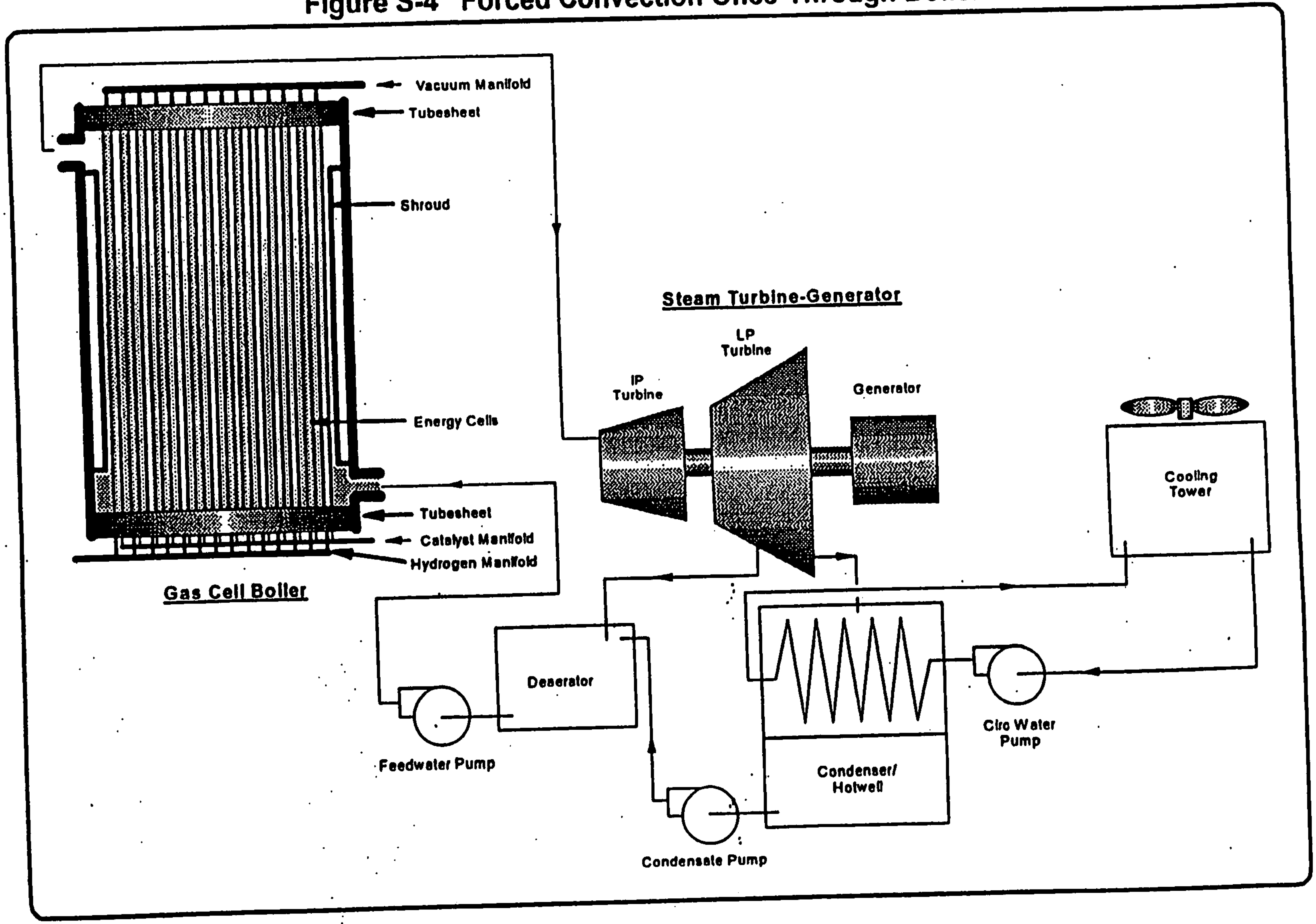
Figure S-4 Forced Convection Once-Through Boiler



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Option S-5 Forced Convection Intermediate Loop Boiler

Precedents

Helium cooled reactor (Peach Bottom, Fort St. Vrain, AVR), or carbon dioxide cooled reactor (Magnox, AGR) primary loop/steam generator.

Summary Description

HydroCatalysis energy cells are placed in tubes penetrating a heat exchanger vessel containing a pressurized gas (e.g., He, CO_2) heat transfer fluid. A gas circulator provides forced convection heat transfer on the shell sides of the heat exchanger and a steam generator. A helical coil once-through steam generator providing superheated steam is shown, but variations could include straight tube units as well as recirculating units providing saturated steam.

Concept Strengths

1. Independent control of energy cell environment (pressure, temperature, flow) over the startup and power operation range
2. Independent design of energy cell heat exchanger to accommodate power density and dynamic characteristics of the HydroCatalysis process

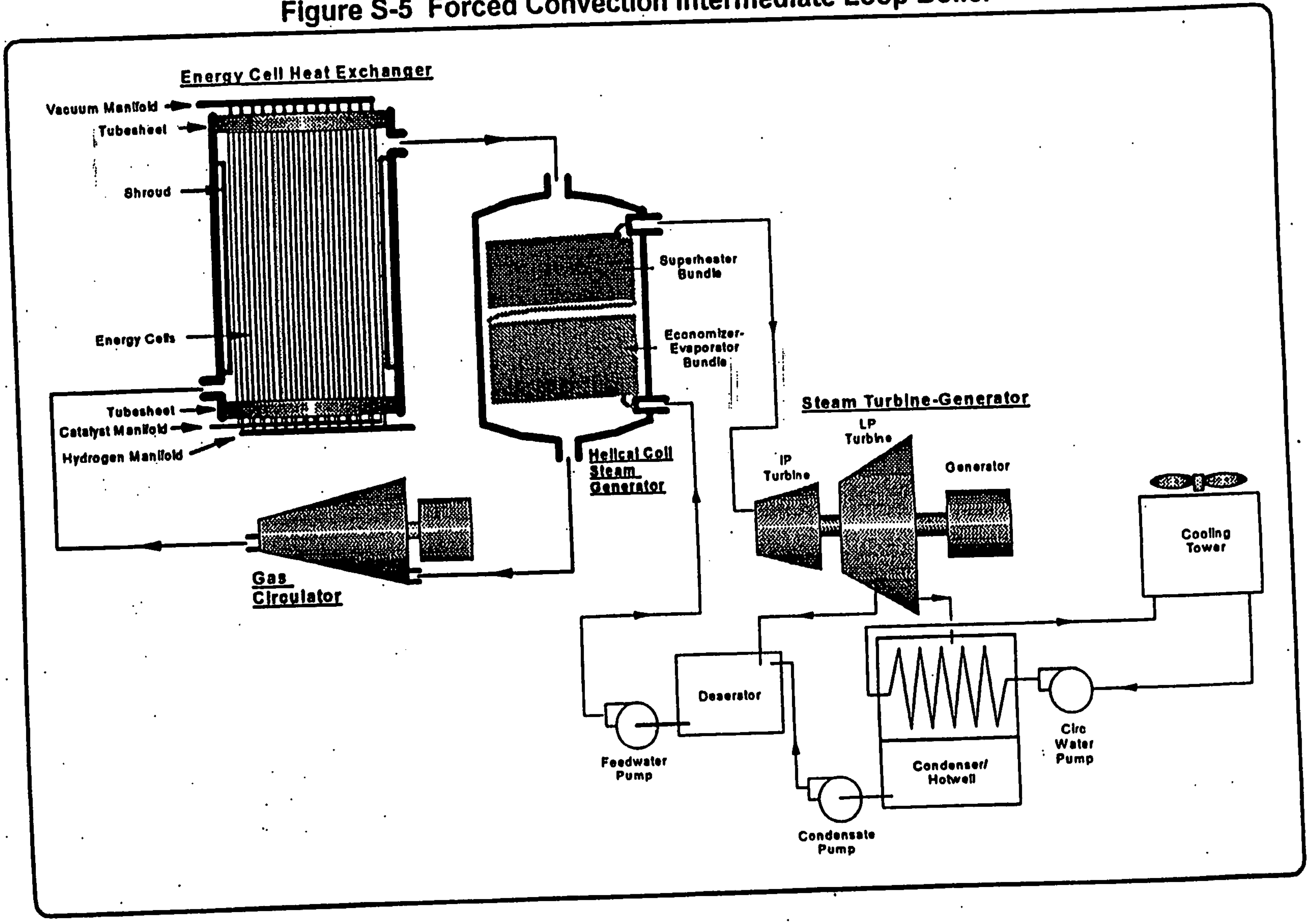
Design Issues

1. Development, capital and operating cost
2. Flow induced static and dynamic loads
3. Achieving self-sustaining energy cell temperature conditions during startup
4. High temperature design of energy cell heat exchanger and steam generator vessel and internals, and accommodation of thermal expansion

Energy Cell Environment

1. External pressure range
2. Temperature distribution and operating range
3. Flowrates and flow induced loads
4. Startup and control requirements

Figure S-5 Forced Convection Intermediate Loop Boiler



Option G-1 Radiant Open Cycle

Precedents

To be identified.

Summary Description

A bank of cylindrical HydroCatalysis energy cells is positioned adjacent to a bank of heat exchanger tubes inside an insulated container with a reflective inner surface. A movable mirror lattice between the energy cells and heat exchanger tubes is used to control heat transfer from the energy cells during startup and power operation. The heat exchanger tubes contain pressurized air, with pressures determined by the characteristics of the gas turbine.

Concept Strengths

1. Low external pressure on energy cells
2. No flow induced structural loads on energy cells
3. Control of energy cell heat losses during startup
4. Simple flow circuit

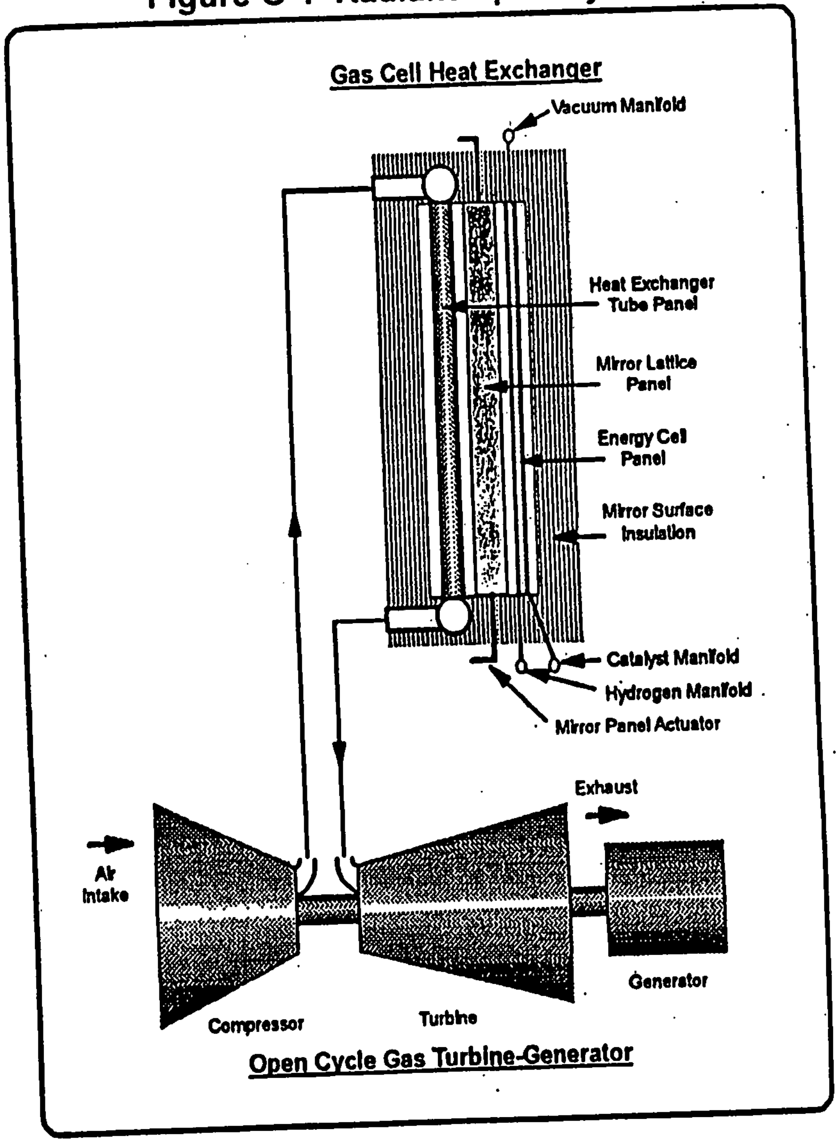
Design Issues

1. Radiant energy cell panel and heat exchanger tube panel heat flux - size requirements
2. Axial variation in heat exchanger tube temperature/heat transfer from energy cells
3. Accommodation of thermal expansion

Energy Cell Environment

1. Temperature distribution and operating range
2. Startup and control requirements

Figure G-1 Radiant Open Cycle



Option G-2 Forced Convection Open Cycle

Precedents

To be identified.

Summary Description

HydroCatalysis energy cells in tubes penetrate a heat exchanger pressure vessel, with pressurized air in crossflow over the tubes. Air from a gas turbine compressor flows to the vessel inlet, and heated air from the vessel outlet flows to the inlet of the power turbine, with pressures determined by the characteristics of the gas turbine. Self-sustaining energy cell temperature conditions are achieved during startup by combustion of hydrogen on the shell side of the heat exchanger, analogous to operation of conventional combustion turbines.

Concept Strengths

1. Potential for rapid startup using combustion bootstrap
2. Effective energy cell heat removal - relatively compact design
3. Simple flow circuit

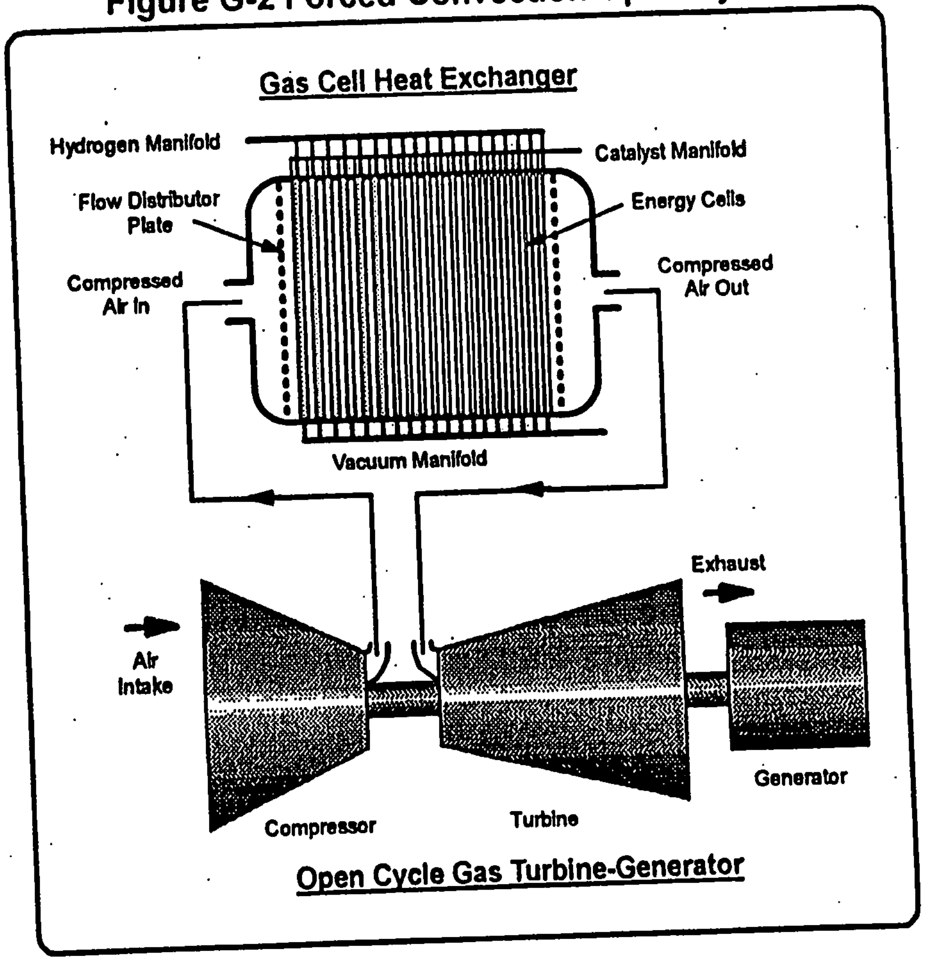
Design Issues

1. Flow induced static and dynamic loads on energy cell tubes
2. Accommodation of thermal expansion and air temperature rise across heat exchanger
3. Energy cell dynamic response requirements
4. High temperature design of gas cell heat exchanger vessel and internals

Energy Cell Environment

1. External pressure range
2. Temperature distribution and operating range
3. Flowrates and flow induced loads
4. Startup and control requirements

Figure G-2 Forced Convection Open Cycle



Option G-3 Forced Convection Intermediate Loop Open Cycle

Precedents

Externally Fired Combined Cycle demonstration project at Pennsylvania Electric Company Warren Station, developed by Hague International in cooperation with Black & Veatch, Foster Wheeler, and Allison Engine Company.

Summary Description

HydroCatalysis energy cells are placed in tubes penetrating a heat exchanger vessel containing a pressurized gas (e.g., He, CO_2) heat transfer fluid. A gas circulator provides forced convection heat transfer on the shell side of the energy cell heat exchanger and the tube side of a gas/air heat exchanger. Pressurized air from a gas turbine compressor flows to the shell side of the gas/air heat exchanger and heated air returns to the inlet of the power turbine.

Concept Strengths

1. Independent control of energy cell environment (pressure, temperature, flow) over the startup and power operation range
2. Independent design of energy cell heat exchanger to accommodate power density and dynamic characteristics of the HydroCatalysis process

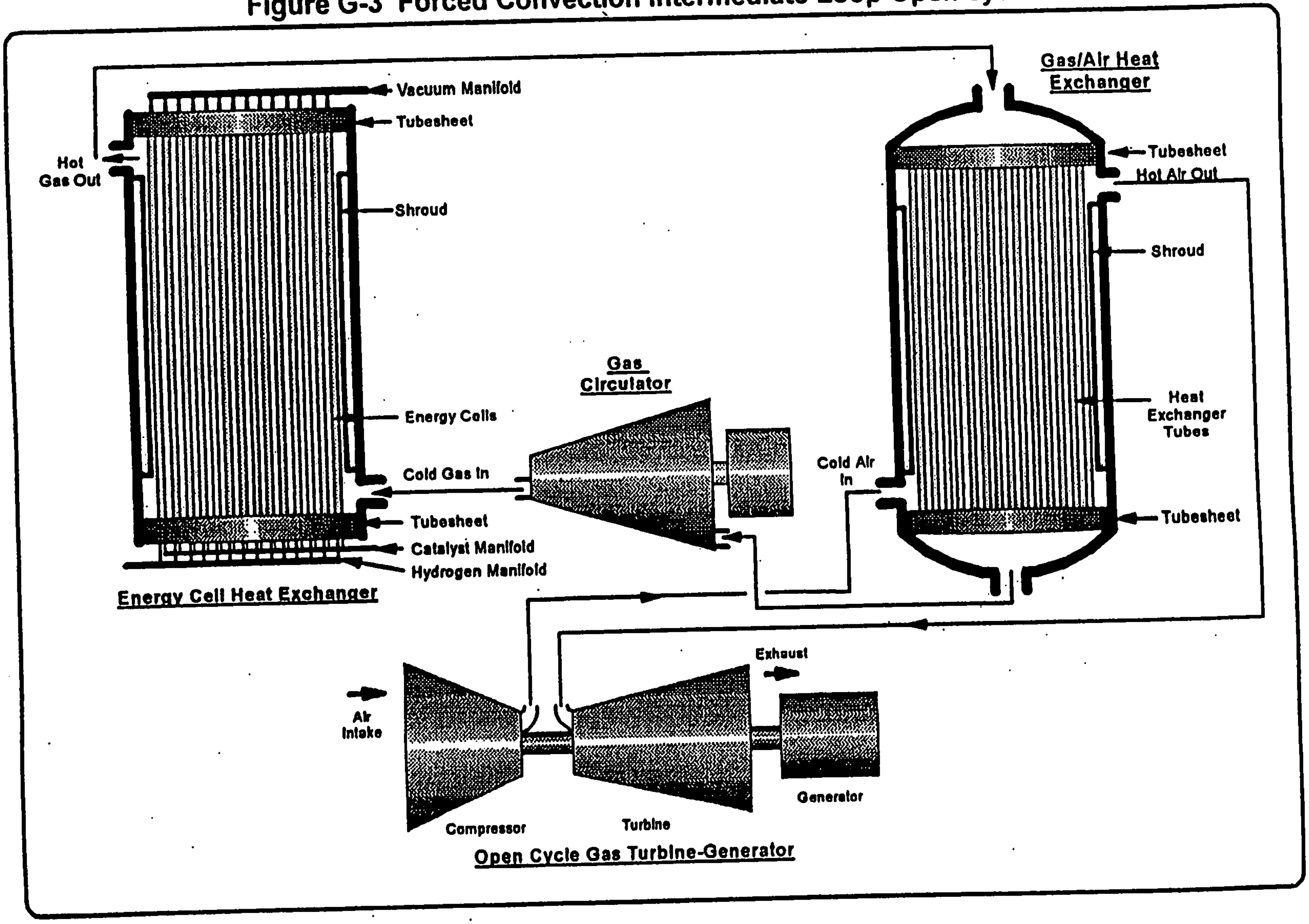
Design Issues

1. Capital and operating cost
2. Flow induced static and dynamic loads
3. Achieving self-sustaining energy cell temperature conditions during startup
4. High temperature design of energy cell heat exchanger and gas/air heat exchanger vessel and internals, and accommodation of thermal expansion

Energy Cell Environment

1. External pressure range
2. Temperature distribution and operating range
3. Flowrates and flow induced loads
4. Startup and control requirements

Figure G-3 Forced Convection Intermediate Loop Open cycle



Option G-4 Radiant Closed Cycle

Precedents

Oberhausen II helium turbine plant, HHV gas turbine test facility (Germany).

Summary Description

A bank of cylindrical HydroCatalysis energy cells is positioned adjacent to a bank of heat exchanger tubes inside an insulated container with a reflective inner surface. A movable mirror lattice between the energy cells and heat exchanger tubes is used to control heat transfer from the energy cells during startup and power operation. The heat exchanger tubes contain pressurized gas (e.g., helium), with pressures determined by the characteristics of the gas turbine cycle.

Concept Strengths

1. Low external pressure on energy cells
2. No flow induced structural loads on energy cells
3. Control of energy cell heat losses during startup
4. Controlled pressure, chemistry environment of turbine blades and heat exchanger tubes

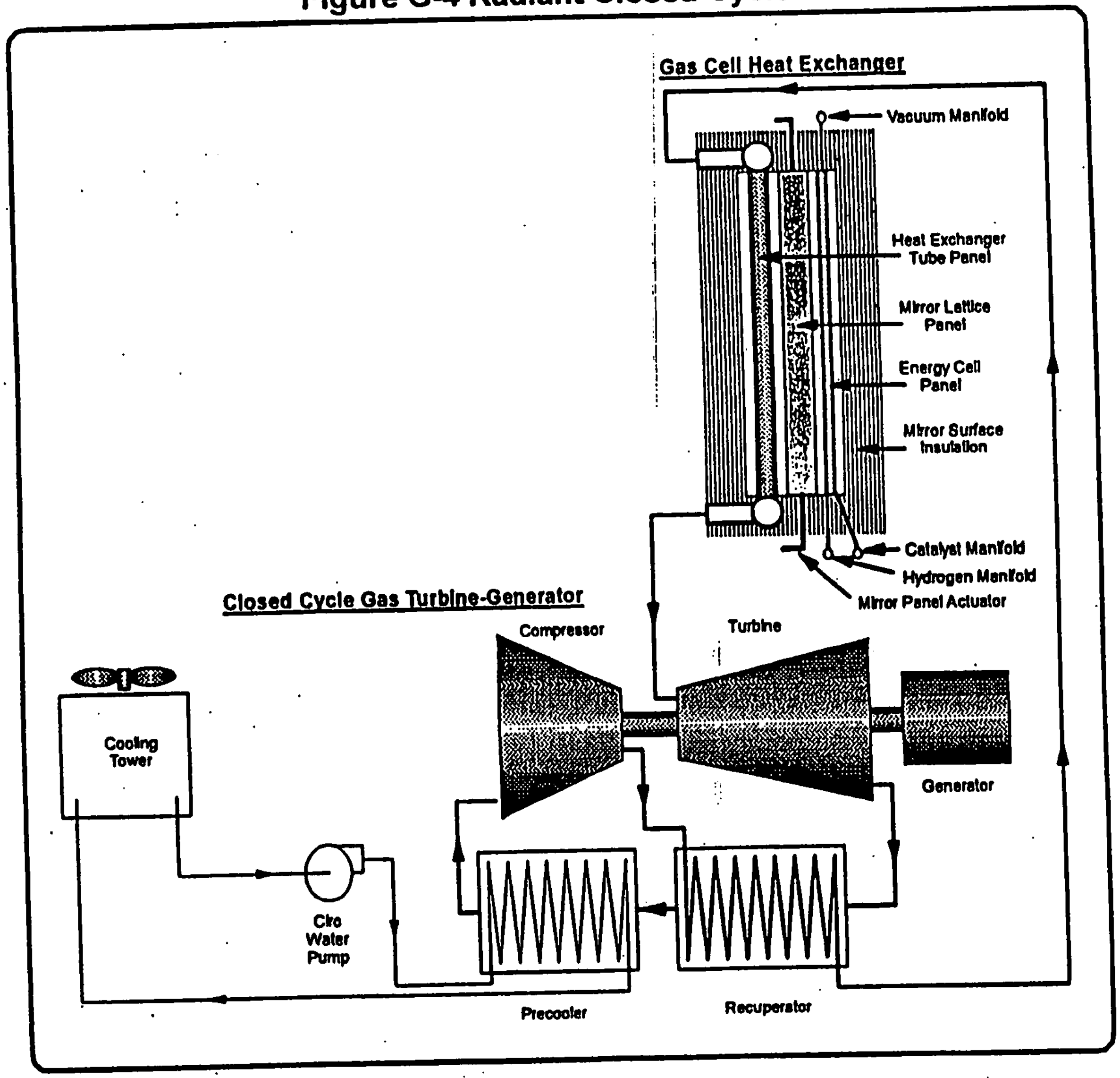
Design Issues

1. Development, capital and operating costs
2. Radiant energy cell panel and heat exchanger tube panel heat flux - size requirements
3. Axial variation in heat exchanger tube temperature/heat transfer from energy cells
4. Accommodation of thermal expansion

Energy Cell Environment

1. Temperature distribution and operating range
2. Startup and control requirements

Figure G-4 Radiant Closed Cycle



Option G-5 Forced Convection Closed Cycle

Precedents

Oberhausen II helium turbine plant, HHV gas turbine test facility (Germany).

Summary Description

HydroCatalysis energy cells in tubes penetrate a heat exchanger pressure vessel, with pressurized gas (e.g., helium) in crossflow over the tubes. Gas from a gas turbine compressor flows through a recuperator heat exchanger to the vessel inlet, and heated gas from the vessel outlet flows to the inlet of the power turbine. The gas pressure is determined by the characteristics of the gas turbine cycle.

Concept Strengths

1. Effective energy cell heat removal - relatively compact heat exchanger design
2. Controlled pressure, chemistry environment of turbine blades and heat exchanger tubes

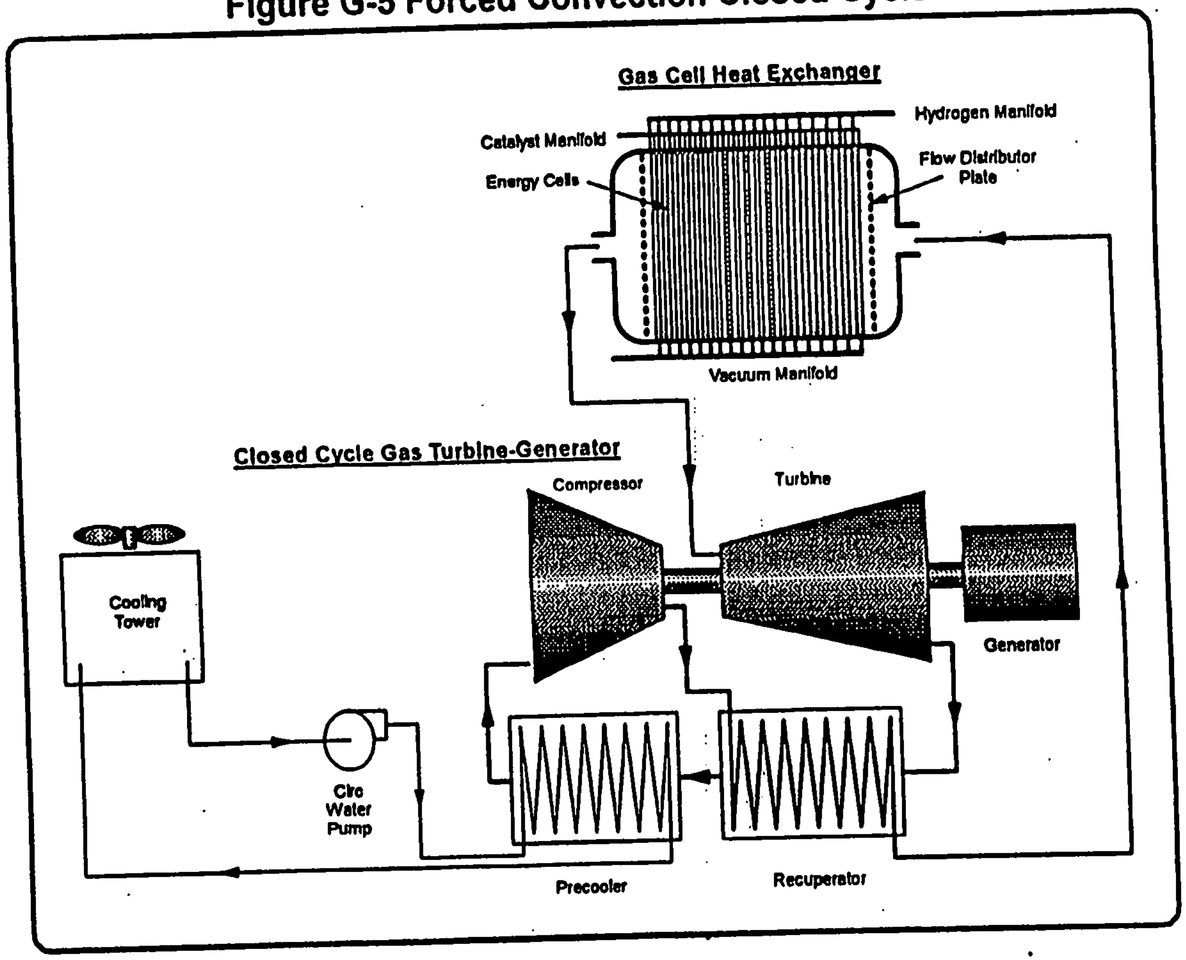
Design Issues

1. Development, capital and operating costs
2. Achieving self-sustaining energy cell temperature conditions during startup
3. Flow induced static and dynamic loads on energy cell tubes
4. Accommodation of thermal expansion and gas temperature rise across heat exchanger
5. High temperature design of gas cell heat exchanger vessel and internals
6. Energy cell dynamic response requirements

Energy Cell Environment

1. External pressure range
2. Temperature distribution and operating range
3. Flowrates and flow induced loads
4. Startup and control requirements

Figure G-5 Forced Convection Closed Cycle



Attachment F

"S-1 Radiant Recirculating Boiler" (Technology Insights).

S-1 Radiant Recirculating Boiler

S-1.0 Summary

Precedents

ABB/Combustion Engineering, Foster Wheeler oil, gas and coal fired steam boilers.

Summary Description

A bank of cylindrical HydroCatalysis energy cells is positioned adjacent to a bank of boiler tubes inside an insulated container with a reflective inner surface. A movable mirror lattice between the energy cells and boiler tubes is used to control heat transfer from the energy cells during startup and power operation. The boiler circuit is a natural convection recirculating loop with a steam drum containing steam separation equipment to meet the minimum inlet steam quality requirements of the turbine.

Concept Strengths

1. Low external pressure on energy cells
2. No flow induced structural loads on energy cells
3. Control of energy cell heat losses during startup
4. Boiler tube temperature relatively constant over the tube length and over the load range

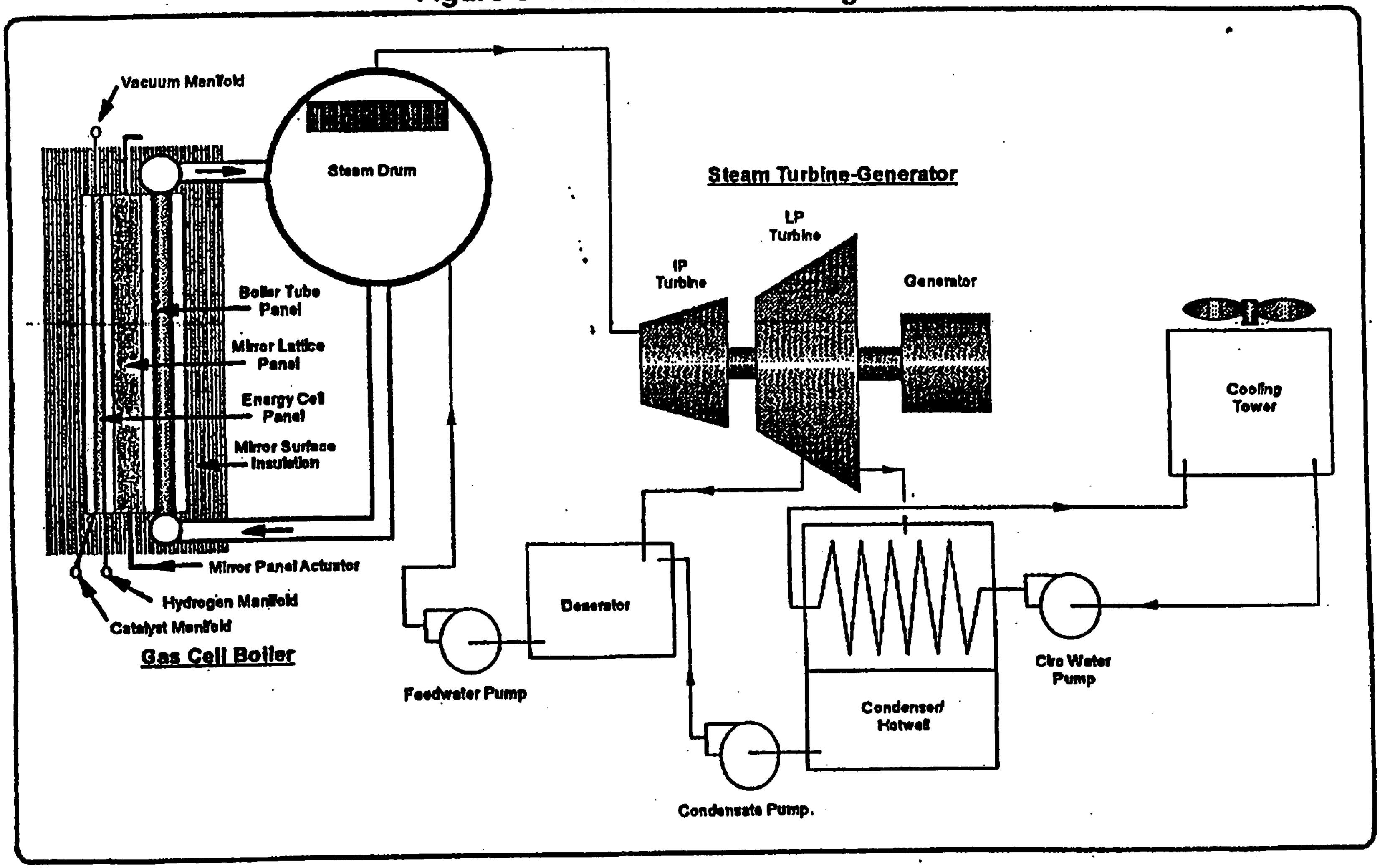
Design Issues

1. Accommodation of thermal expansion
2. Energy cell temperature variation characteristics over the load range
3. Radiant panel heat flux - size requirements

Energy Cell Environment

1. Temperature distribution and operating range
2. Startup and control requirements

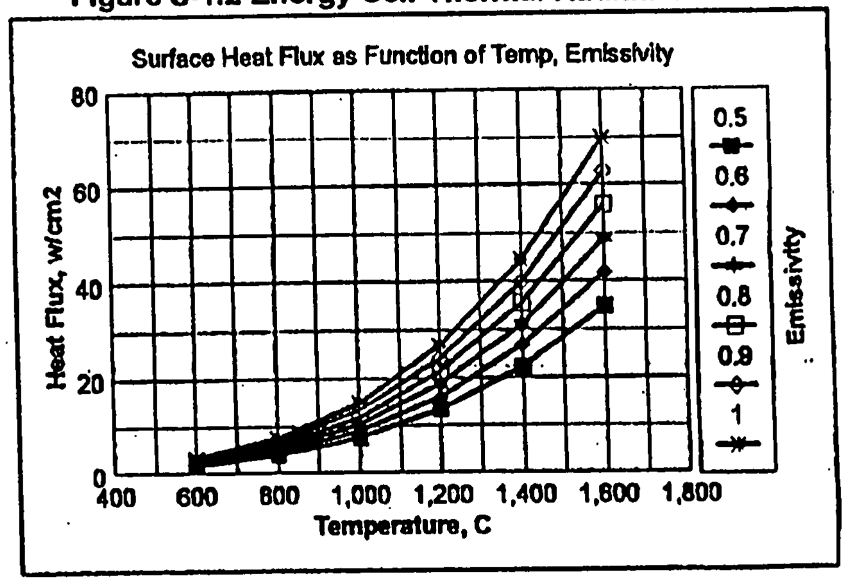
Figure S-1 Radiant Recirculating Boiler



S-1.1 Thermal Analysis

Heat transfer for the radiant concept can be approximated by neglecting convection and treating the energy cell and boiler tube panels as gray bodies. This results in radiation from the energy cell surface given by the expression:

Figure S-1.2 Energy Cell Thermal Radiation Flux



$E_g = \epsilon_g \sigma T^4$, where

E_g = Gray body emissive power, watts/cm^2

ϵ_g = Surface emissivity

σ = Stefan-Boltzman constant = 5.675×10^{-12} watts/cm^2-°K^4

T = Surface Temperature, °K

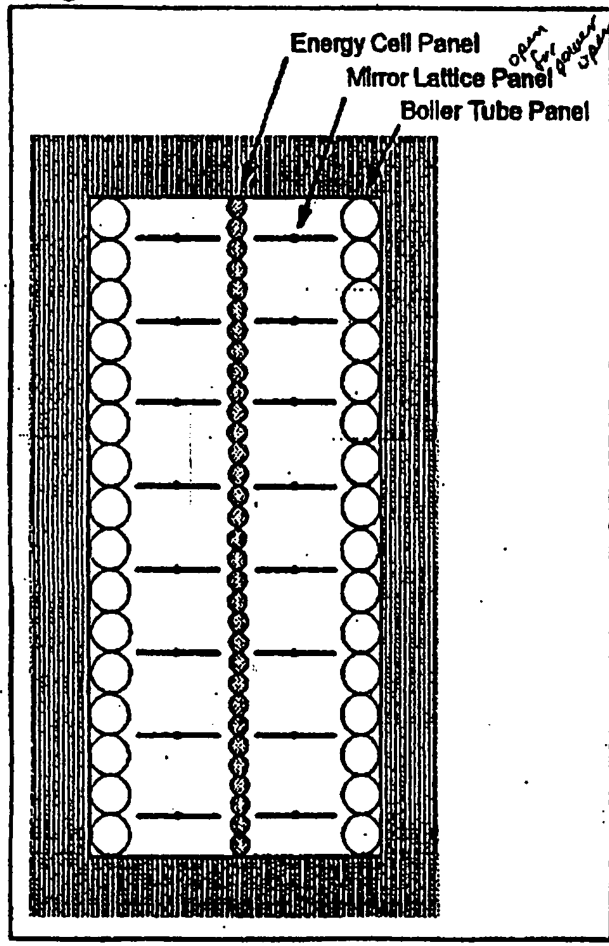
For the temperature range likely to be of interest for the energy cell panels, the resulting thermal radiation flux as a function of surface temperature and emissivity is shown in Figure S-1.2.

Calculating the exact net radiation heat transfer between the two surfaces is a complex geometric problem requiring detailed descriptions of the energy cell and boiler tube panels, the mirror lattice and chamber walls. However, to a first approximation the heat transfer can be estimated by treating the system as a 1 dimensional configuration with equivalent surface area corresponding to the frontal surface of the energy cell and boiler tube panels. Under these assumptions, the net heat transfer per unit panel frontal surface area is given by

$E_{net} = (E_{g,1} - E_{g,2})\, F_{1-2} = \sigma F_{1-2} (\epsilon_{g,1} T_1^4 - \epsilon_{g,2} T_2^4)$, where

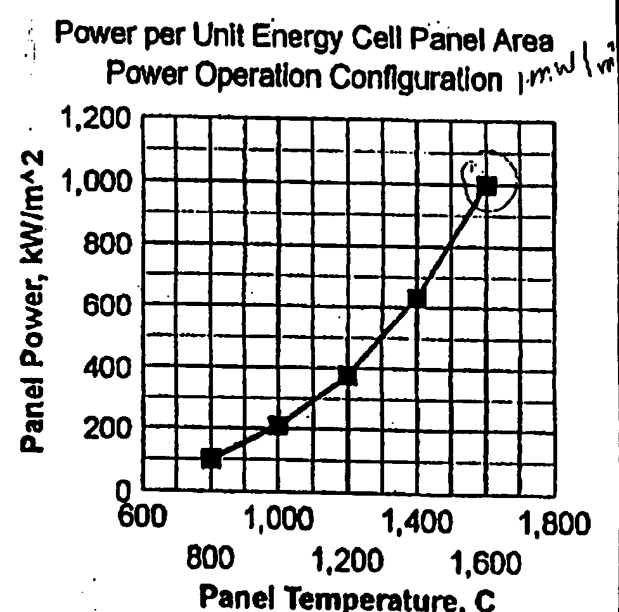
Subscripts 1 and 2 refer to the energy cell and boiler tube panel surfaces respectively
F_{1-2} = Geometric shape factor for radiation between surfaces 1 and 2 ($F_{1-2} = F_{2-1}$ since the areas are equal)

Figure S-1.3 Horizontal Cross Section



A horizontal cross section of a radiant recirculating boiler concept consistent with the system diagram shown in Figure S-1.1 is shown in Figure S-1.3. In this diagram, the energy cells are assumed to be vertical tubes aligned in the center of an insulated chamber with a reflective inner surface. The boiler tubes are placed along the two walls of the chamber opposite the energy cell panel. A lattice of mirrors between the energy cells and boiler tubes would be in the open position for power operation as shown in the figure. Larger units may consist of alternating energy cell and boiler tube panels, with interior boiler tube panels receiving radiant heat from energy cell panels on both sides.

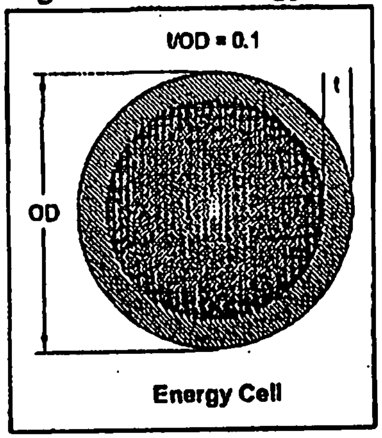
Figure S-1.4 Boiler Performance



1. Steam Pressure - 1000 psig
2. Energy cell, boiler emissivities - 0.9
3. Equivalent linear shape factor - 0.8

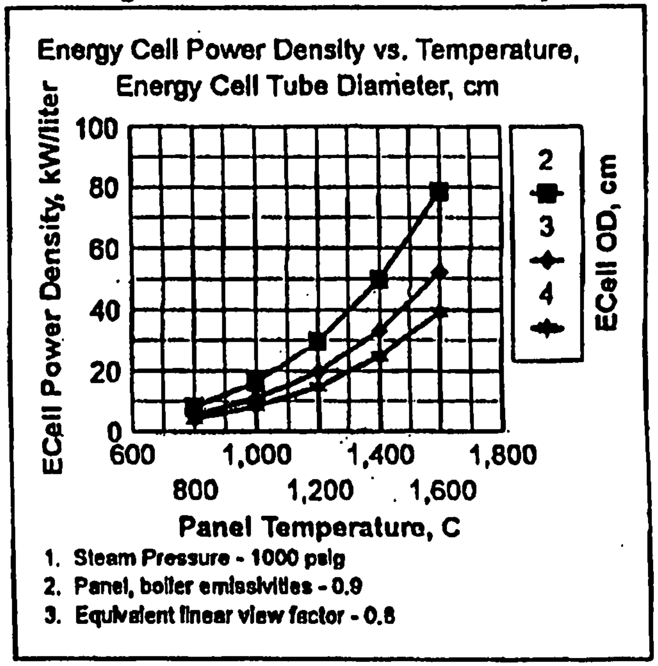
The heat transfer performance as a function of energy cell panel temperature for a representative set of conditions was estimated using the assumptions discussed on the previous page. A steam pressure of 1,000 psig was selected as a reference, with lower pressures having a negligible effect on the results. Energy cell and boiler panel emissivities of 0.9 were selected as practical, achievable values. An equivalent linear shape factor of 0.8 was selected as a reasonable and likely conservative representation of the configuration. The results show a factor of 10 variation in heat transfer over the 800-1600°C energy cell panel surface temperature range, with a maximum value of approximately 1

Figure S-1.5 Energy Cell



megawatt per square meter of energy cell panel frontal surface area. The HydroCatalysis cell energy density requirements for this concept are determined by the cell interior volume per unit frontal surface area. This was estimated assuming the energy cells are in the form of cylindrical tubes with a wall thickness equal to 10% of the tube outside diameter and the reaction zone encompassing the entire interior volume, as shown in Figure S-1.5. In this configuration, the energy cell reaction zone volume per unit panel frontal area is proportional to the tube diameter. The required power density to produce the heat transfer performance shown in Figure S-1.4 was calculated as a function of energy cell tube outside diameter, with results as shown in Figure S-1.6. The heat exchanger performance and energy cell power densities shown in Figures S-1.4 and S-1.6 illustrate the inherent response characteristics of this concept. As such, they illustrate how the unit may operate over the load range. For example, if a minimum load of 20% of rated power were used, the energy cell panel would be brought to a temperature of approximately 1,000°C (as indicated by Figure S-1.4) to establish stable power operation at the low end of the range. Increasing the energy cell power level would result in increasing cell temperatures, reaching a maximum operating cell temperature of 1,600 °C at full rated power. Under full power conditions, the maximum surface heat flux at the boiler tubes would be approximately 500 kW/m^2 (half the bidirectional frontal area power of the cell panel), compared to a burnout heat flux (transition from annular to mist flow) estimated to be well in excess of 3,000 kW/m^2.

Figure S-1.6 Cell Power Density

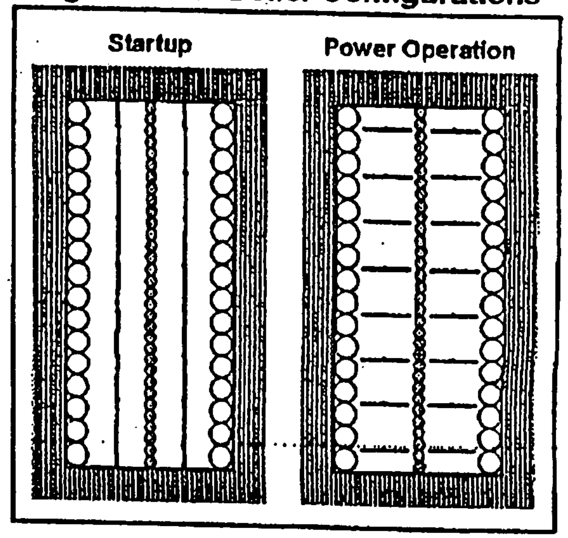


S-1.2 Operational Considerations

A primary operational consideration is the startup of the unit. As currently understood, the HydroCatalysis cells are expected to require an elevated temperature in the reaction zone (i.e., ~1,000°C) to achieve self-sustaining energy

production. The concept provides for thermal isolation of the energy cells from the heat sink (boiler tubes) for heatup to minimum initial temperatures. The approach, as illustrated in Figure S-1.7, is
to rotate the mirror lattice panel for startup to isolate the energy cell panel in a reflective enclosure. This will substantially reduce the amount of energy required to bring the energy cells to initial operating temperature. Heating up the energy cells to self-sustaining temperatures could be accomplished either by combustion of hydrogen in the region around the boiler, or resistance heating of the energy cell panel. Combustion could be faster and cheaper, but may pose problems with fouling the mirrors, while resistance heating would be clean, but would present design problems with connecting electrical leads. Once the HydroCatalysis conditions are achieved, energy cell panel temperatures could be controlled by a combination of hydrogen and catalyst concentrations and positioning of the mirror panels. In the power operation range the mirror panels would likely be in a full open position.

Figure S-1.7 Boiler Configurations



The thermal analysis shows that the energy cell panel and the boiler would be essentially decoupled, with the heat losses from the energy cell panel insensitive to the boiler panel temperature. Thus the controls for the reaction process and the boiler would be effectively independent, with supervisory level control to maintain the balance of heat generation and removal. The stability of the recirculating boiler, resulting from the large water thermal mass and mixing of incoming feedwater with recirculating saturated liquid, and expected large margins to boiling limits will simplify the boiler control requirements with regard to meeting turbine load demands. The relatively small thermal mass of the energy cell panel may make for more challenging control requirements on power generation to maintain the panel within temperature limits, depending on the dynamic characteristics of the HydroCatalysis process.

S-1.3 Development Requirements

Outside the technology development required to determine the static and dynamic characteristics and limitations of the HydroCatalysis process, much of the work to be done to develop this concept would be expected to be addressing conventional engineering design issues or modifications of existing designs. The boiler tube panel would be very similar to the economizer/evaporator section of a conventional recirculating water wall fossil boiler, with less challenging environmental conditions. Boiler controls and the balance of the power conversion system should be commercially

available. The energy cell panel would require considerable design development and component testing to address issues such as accommodation of high temperatures and thermal expansion; routing and valving of the hydrogen and vacuum manifolds; and routing, valving, heat tracing and partial pressure control of the catalyst manifold. Design of the energy cell controls will need to address balancing the cells for uniform power production as well as providing stable dynamic response as required by the supervisory control system and material limits of the panels. Design of the equipment and controls for heating the energy cell panel to minimum power operating conditions on startup will also require unique new design development.

S-1.4 Economic Assessment